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MECHANICAL IMPACT SYSTEM DESIGN FOR ADVANCED SPACECRAFT (MISDAS)

APPLICATION TO AES SPACECRAFT

Contract NAS9-4915, Modification 2

March 25, 1966

Prepared by

A I Bernstein

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Project Manager MISDAS

Approved by

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Director, Structures and Dynamics

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FOREWORD

This document presents the results of a study of the application of the Mechanical Impact System Design for Advanced Spacecraft (MISDAS) to the AES-type spacecraft. The study was conducted by the Space and Information Systems Division of North American Aviation, Inc. for the Manned Spacecraft Center of the National Aeronautics and Space Administration under Contract NAS9-4915, Modification 2, dated December 22, 1965. The MISDAS study is being performed by S&ID under the technical cognizance of J. McCullough of the Mechanical and Landing Systems Branch, NASA/MSFC. The work was performed by a team of Research and Engineering personnel, and coordinated with Apollo and AES Engineering in those areas where implementation of the land impact system could influence vehicle design, cost, or schedule.

This report was prepared by A.I. Bernstein, Project Manager, NAA/S&ID. Major contributors were A.S. Musicman, Project Engineer; H. Bransky, E.M. Van Alstyne, and R.S. Barr, Design Engineers; J. Partin and D. Herting, Dynamic Engineers; C.C. Haynie, Manufacturing Engineer; W.A. Bateman, Structures Engineer; and A. Kusano, Weights Engineer.

TECHNICAL REPORT INDEX/ABSTRACT

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	UNCLASSIFIED

TITLE OF DOCUMENT
MECHANICAL IMPACT SYSTEM DESIGN FOR ADVANCED SPACECRAFT
APPLICATION TO AES SPACECRAFT

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DESCRIPTIVE TERMS

*APOLLO, AES, ENTRY VEHICLES,
*EARTH LANDING SYSTEMS,
*LANDING STABILITY,
*LANDING IMPACT ATTENUATION

ABSTRACT N67-14939

THE PRIMARY OBJECTIVE OF THIS STUDY IS THE PRELIMINARY DESIGN OF A MECHANICAL IMPACT ATTENUATION SYSTEM FOR EARTH LANDING OF ADVANCED APOLLO-TYPE SPACECRAFT. THE SYSTEM IS TO BE ADAPTABLE TO APOLLO WITH MINIMUM MODIFICATION, AND MUST ABSORB LANDING IMPACT, PROTECT CREW AND STRUCTURE FROM EXCESSIVE FORCES, PREVENT OVERTURNING OF THE SPACECRAFT, AND PERMIT SPACECRAFT REUSE WITH MINOR REFURBISHMENT. THIS DOCUMENT PRESENTS THE RESULTS OF A STUDY OF THE FEASIBILITY OF INCORPORATING THE MECHANICAL IMPACT SYSTEM IN THE AES SPACECRAFT. DESIGN LAYOUTS STUDIES, STRUCTURAL ANALYSES, LANDING STABILITY ANALYSES, AND MANUFACTURING EVALUATIONS WERE PERFORMED. TWO CONCEPTS WERE CONSIDERED - ONE USING A DEPLOYED AFT HEAT SHIELD AND RADIAL SKIDS, THE OTHER EMPLOYING A HINGED SEGMENTED HEAT SHIELD. INCORPORATION OF EITHER SYSTEM IS POTENTIALLY FEASIBLE. A PRELIMINARY DEVELOPMENT AND QUALIFICATION PROGRAM IS PRESENTED.

Author

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TABLES

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INTRODUCTION

The Space and Information Systems Division (S&ID) of North American Aviation, Inc. (NAA), under contract to the National Aeronautics and Space Administration, Manned Spacecraft Center (NASA/MSC) has initiated development of an earth landing system for advanced Apollo-type spacecraft. Contract NAS9-4915 is a preliminary design study to select a landing impact-absorption system that (1) can be incorporated in the Apollo command module with minimum structural modification, (2) will provide a stable landing platform, (3) will prevent vehicle overturning and damage to the structure, and (4) will permit the spacecraft to be reused with refurbishment after each landing. The study, which encompasses preliminary design and limited stability analyses of candidate systems, is concerned with mechanical systems (i.e., devices that require contact with the landing surface to absorb impact energy).

In Phase I, completed September 20, 1965, preliminary design, stability, and structural evaluations of candidate design concepts were conducted. These tradeoffs led to the recommendation that two concepts be studied further to identify an optimum system. One concept (Figure 1) employs a six-legged segmented heat shield; the other concept (Figure 2) uses an extended aft heat shield and 12 radially deployed skids. This work was reported in Reference 1.

Phase II of this program encompasses a more detailed design, stability analysis, and structural analysis of the selected concepts. It includes the definition of the impact system, sizing of the primary members, selection of materials and construction, analytical verification of the stability envelope, definition of modifications required in the spacecraft structure for the design conditions and for higher descent velocities, and preliminary formulation of a program for development and qualification of the selected system.

Modification 2 of the MISDAS contract, reported herein, requires a study of the application of the two landing systems identified in Phase I to an AES-type vehicle. The study includes the preliminary design, structural analysis, and stability analysis of the two landing systems using the AES spacecraft specified weight, landing velocities, and spacecraft attitudes; preliminary study of the relocation of equipment in the aft compartment of AES installation and deployment of the retrorocket systems; and preliminary manufacturing and program development studies. The detailed stress calculations are presented in Appendix A of this report.

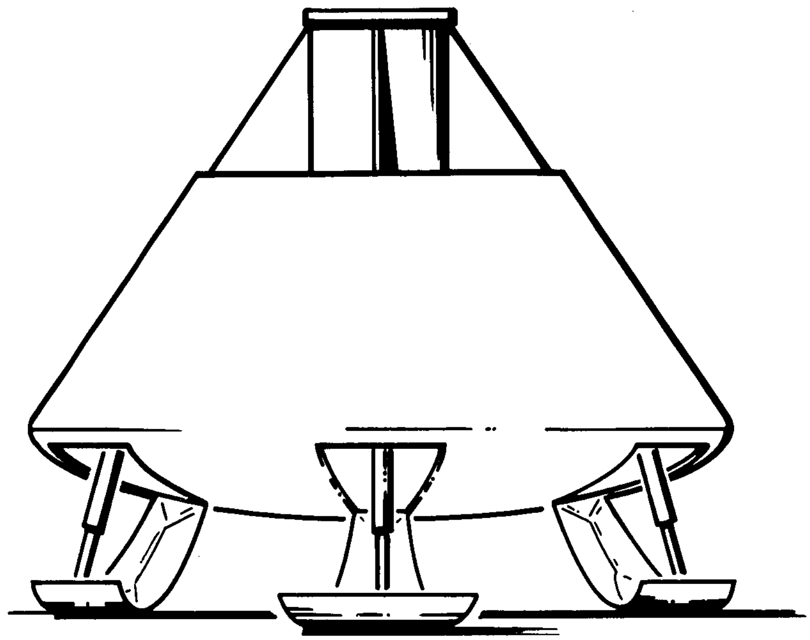


Figure 1. Six-Legged Gear Design

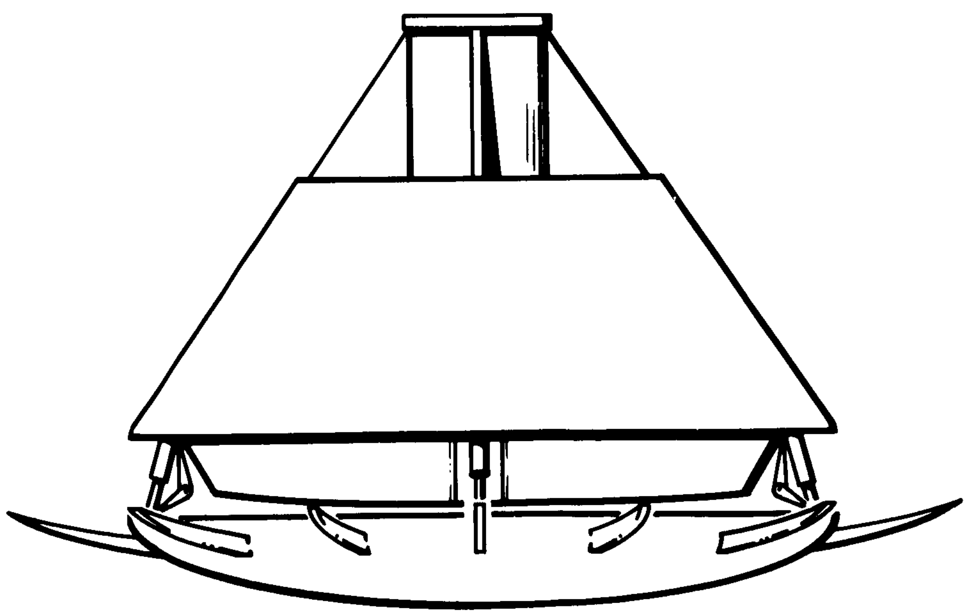


Figure 2. Deployable Heat Shield, Radially Extended Skids

To perform landing stability studies, analytical programs were developed that calculate and record the motion of the spacecraft about three axes as a function of time after ground contact. The programs consider variation in spacecraft vertical and horizontal velocity, attitude and orientation, shock strut load-stroke characteristics, and ground coefficient of friction. The stability analysis of the legged vehicle was performed employing a new computer program which describes the vehicle's motion about three axes. The Apollo two-body stability analysis computer program was modified to describe the geometry of the vehicle with deployed heat shield and radial skids. The stability investigations indicated that both design concepts can perform stable landings over the specified design envelope of horizontal and vertical velocities, landing attitudes, and ground conditions.

The design drawings and analyses presented in this report identify major members of each MISDAS installation, the retrorocket systems, materials, and structural member sizes. The stress and weights analyses indicate that the six-legged segmented heat shield concept can be incorporated in AES for a vehicle weight increase of 556 pounds; the radially deployed skid concept would require a weight increase of 737 pounds. Preliminary manufacturing and program development studies indicate that both systems appear to be technically feasible and capable of development and qualification in about the same time span.

A development program for MISDAS application is also presented. Specific areas recommended for follow-on include the development of segmented heat shields, extension of the stability analysis programs to incorporate the response of the ground-to-vehicle impact, and utilization of scale-model tests to verify the MISDAS/AES vehicle stability envelope.

The study of the Application of MISDAS to AES was to determine the structural aspects and landing dynamic characteristics of a MISDAS system for an AES-type spacecraft. The design criteria established were not intended to encompass the complete AES operational requirements. The effects of system failure, such as single retrorocket failure and subsequent effect on spacecraft stability, failure of the heat shield to extend, etc., were not within the scope of this study. These factors must be analyzed more thoroughly before a system design can be selected for incorporation on AES.

The final report of this contract will contain analyses of the 14000 pound spacecraft originally considered, effects of higher rates of descent and coefficients of friction, and complete stability analyses of the MISDAS system.

GUIDELINES, CONSTRAINTS, AND DESIGN CRITERIA

To evaluate installation of MISDAS in AES, the specific guidelines, constraints, and design criteria listed below were established. These criteria define the basic spacecraft geometry, landing conditions, stability requirements, acceleration limits, vehicle performance, ground surface properties, and material properties used in the study.

MISDAS DESIGN REQUIREMENTS

Design requirements for MISDAS are as follows:

1. The system will require contact with the landing surface to absorb impact energy.
2. The system will be stowed during flight and deployed prior to landing.
3. Deployment time is not to exceed 30 seconds.
4. The system will be designed for maximum reliability, simplicity, and efficiency.
5. The vehicle will not overturn during landing and shall not sustain damage to the inner structure.
6. The established crew tolerances for impact accelerations and onset rates will not be exceeded.
7. Design will be compatible with the Apollo structural drawings so that a minimum of structural modification is required for stowage and to support loads during impact.
8. The design will be optimized for minimum weight and stowed volume. It is a design goal to restrict the impact system weight to 3.5 percent of the total landing weight of the spacecraft.
9. No part of the system will be located inside the crew compartment.

10. The energy absorbing portion of the system can be designed for minor refurbishing after each landing.

11. Ultimate design loads for the overall system will be 1.33 times greater than those experienced while landing under the worst combination of the following performance criteria. Ultimate design loads for components which impact the ground shall be equal to those experienced while landing under the worst combination of the following performance criteria.

PERFORMANCE CRITERIA

Performance criteria for MISDAS and AES are as follows:

Item	MISDAS	MISDAS/AES Application
1. Vehicle landing weight	14,000 pounds	10,600 pounds
2. Rate of descent	0 to 15 ft/sec	0 to 15 ft/sec
3. Horizontal velocity	Figure 3	Figure 3
4. Landing surface	Soil and water	Soil and water
a. Ground slope	±5°	±5°
b. Holes and protuberances	±3 inches	—
c. Coefficient of friction	0.35 to 1.0	0.35
5. Spacecraft attitude		
a. Roll	±10°	±10°
b. Pitch	±10°	±10°
c. Yaw	±10°	±10°
d. Suspension angle	27° (Water impact) 0° (Land impact)	
e. Suspension angle tolerance	±2°	±2°

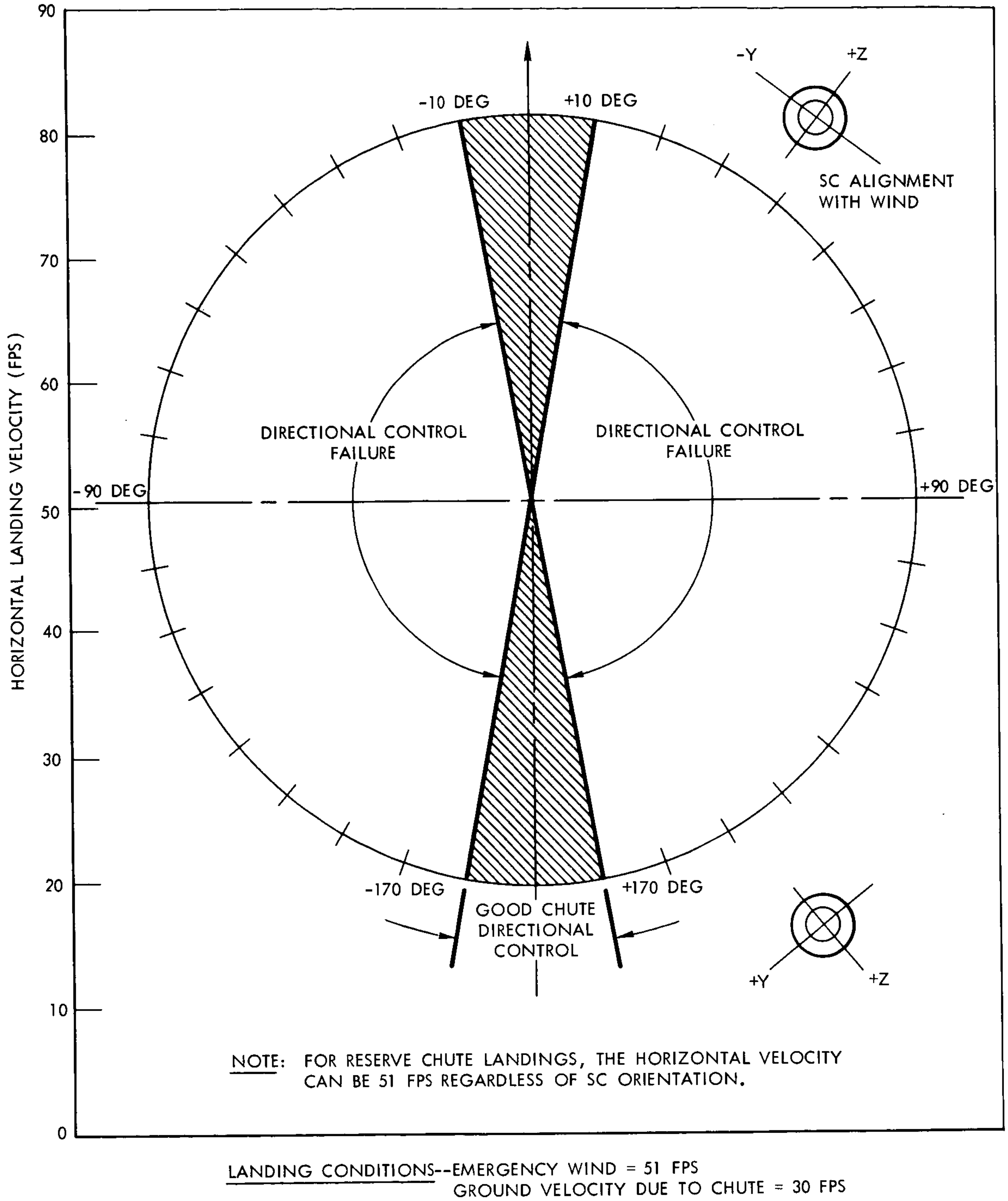


Figure 3. Effect of Spacecraft Alignment With Wind on Horizontal Velocity

It shall be a design goal for the system to accommodate landings of a roll angle of 180 degrees (backwards).

Figure 3 shows the basis for the horizontal velocity and spacecraft attitude criteria. This graph has horizontal velocity plotted as a function of spacecraft alignment with the wind direction (roll). This assumes emergency wind conditions of 51 feet per second and a parachute lift-to-drag ratio of 1, which provides a horizontal velocity of 30 feet per second.

The shaded area of the curve represents the normal landing conditions. At zero-degree roll, or direct alignment into the wind, the horizontal landing velocity would be 81 feet per second, while the vehicle landing at 180 degrees roll, or against the wind, would have a backward velocity of 21 feet per second.

The landing system designed under the subject contract will accommodate all combinations of horizontal velocities and wind alignment conditions shown in Figure 3, in addition to the reserve chute landing conditions. Descending on the reserve chute, the vehicle can land at a horizontal velocity of 50 feet per second, with roll attitude random with respect to wind direction.

SOIL CONDITIONS

All translational motion after initial contact is assumed to be in the form of skidding or sliding, acting parallel to the ground surface. No rebound, soil-vehicle deflection, earth cratering, or variation in the coefficient of friction during the landing sequence is considered.

MATERIAL PROPERTIES

The mechanical and physical properties of structural materials will be the guaranteed minimum values as given in the following documents:

1. MIL-HDBK-5, November 1964 revision (Reference 2)
2. MIL-HDBK-17, June 1965 revision (Reference 3)
3. S&ID Structures Manual, SID 543-G-11, revised December 15, 1965 (Reference 4)

SPACECRAFT DESIGN REQUIREMENTS

The spacecraft, when modified to incorporate the MISDAS system, will be capable of withstanding boost, abort, space environment, and atmospheric entry loads and water impact loads for a vertical velocity of 15 fps at touchdown. These loads are specified in Apollo Requirements Manual ARM-6 (Reference 5). The factors of safety of 1.50 for atmospheric entry and 1.00 for water impact, specified in ARM-6 are applicable to this study.

EVALUATION OF SIX-SEGMENT HEAT SHIELD CONCEPT

DESIGN CHARACTERISTICS

Structural System Description (Figures 4 and 5)

The attenuation system consists of six landing legs, each an identical segment of the command module base, stowed symmetrically within the base. Before impact, these legs are extended downward from inboard hinges by a single hydraulic strut on each leg which also provides dissipation of the impact energy. The landing legs or segments are recessed within the constant heat shield thickness (2 inches) leaving the same unoccupied gap between the heat shield and the spacecraft inner structure as in the current vehicle. The outside face of the landing legs conforms in contour to the base of the spacecraft, presenting an even spherical surface overall to which the aft ablator sections are bonded. Gaps in the heat shield are assumed filled with silicone gasket seals which are bonded to the nonmoving structure. The seals possess sides sloped from the motion of extension to minimize the friction of scrubbing as the landing legs extend. Geometric arrangement of the impact attenuation system was nominally sized for a touchdown clearance of 15 inches for the heat shield.

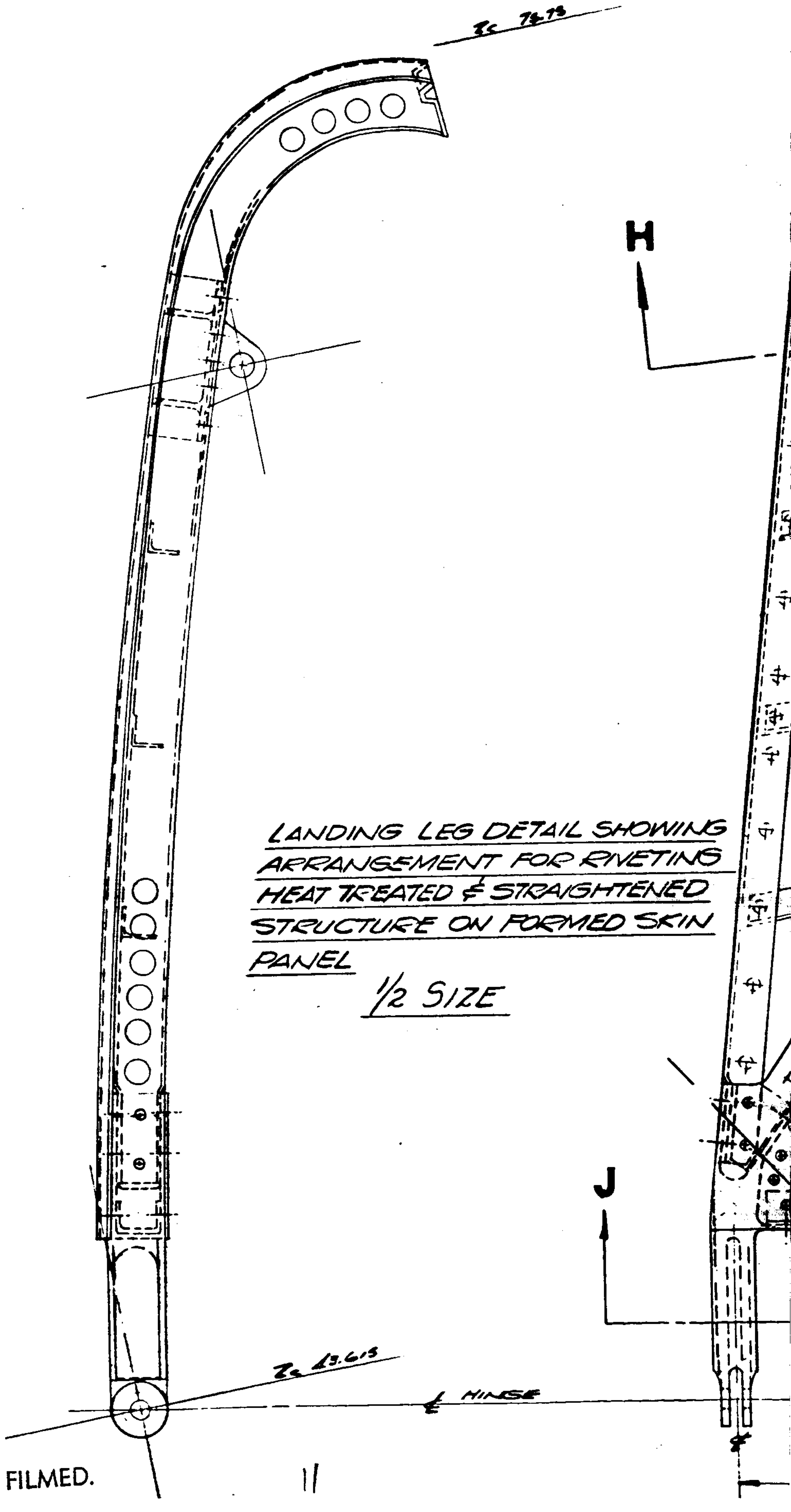
Landing Leg Segments

The extendable legs are sized to be located within recesses in the lower face of the spacecraft heat shield. Their shape conforms to that of the vehicle lower convex surface and the peripheral rim of the command module. The peripheral rim, duplicated on the leg segments, forms a natural skid along the translation vector of landing.

Each landing leg is retained in its stowage recess by an explosive tension bolt on each side which must be released prior to landing system extension. The landing leg design embodies bending material directly connecting the points of load concentration (i.e., the footprint, the attenuation strut rod, and the hinge points on the body). Depth of the bending material at any point remains a constant at 1.44 inches for stowage compatibility in the heat shield.

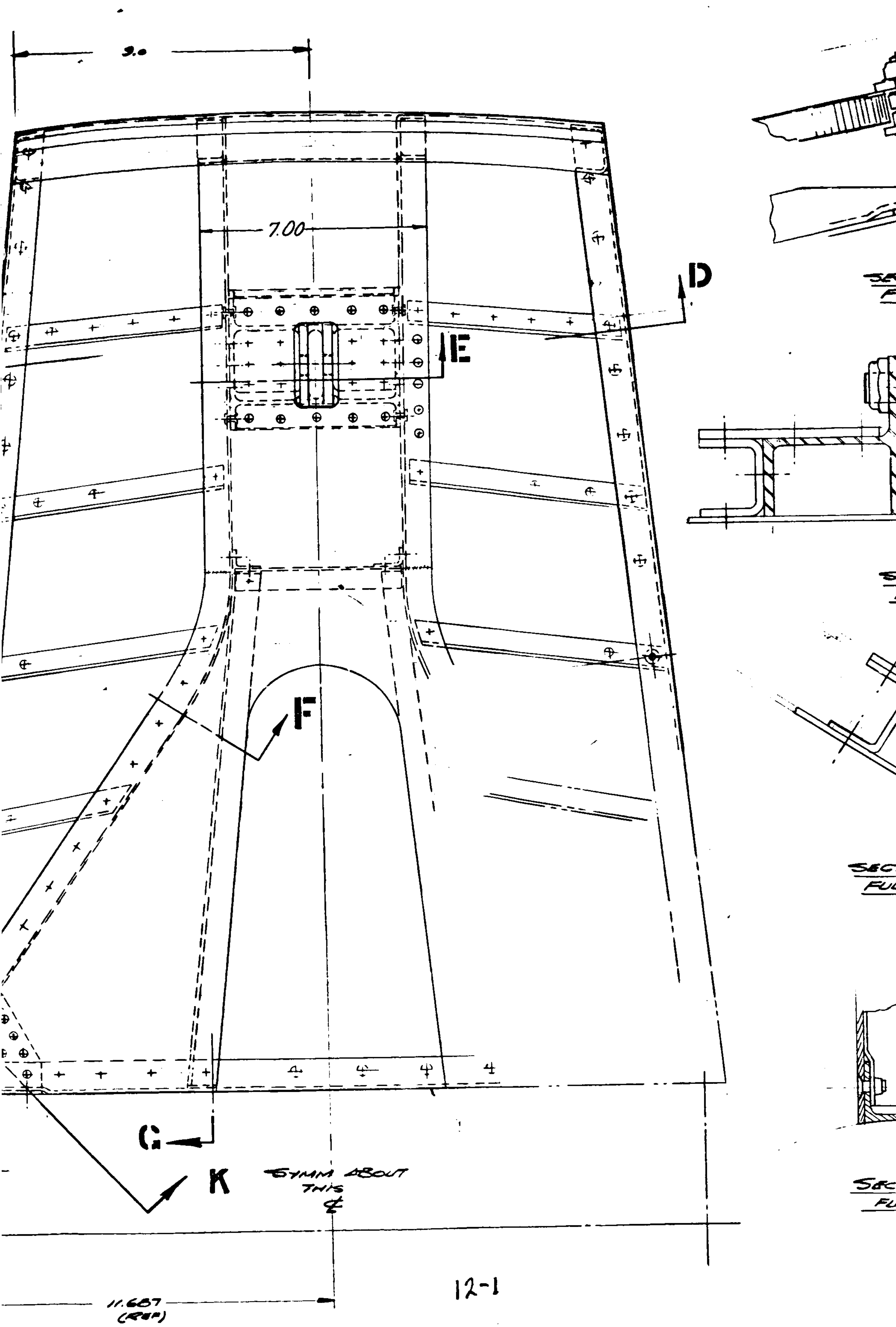
Attenuation System

Dissipation of impact energy in the attenuation system is by the ejection of oil from a hydraulic strut on each of the six landing leg segments



LANDING LEG DETAIL SHOWING ARRANGEMENT FOR RIVETING HEAT TREATED & STRAIGHTENED STRUCTURE ON FORMED SKIN PANEL

1/2 SIZE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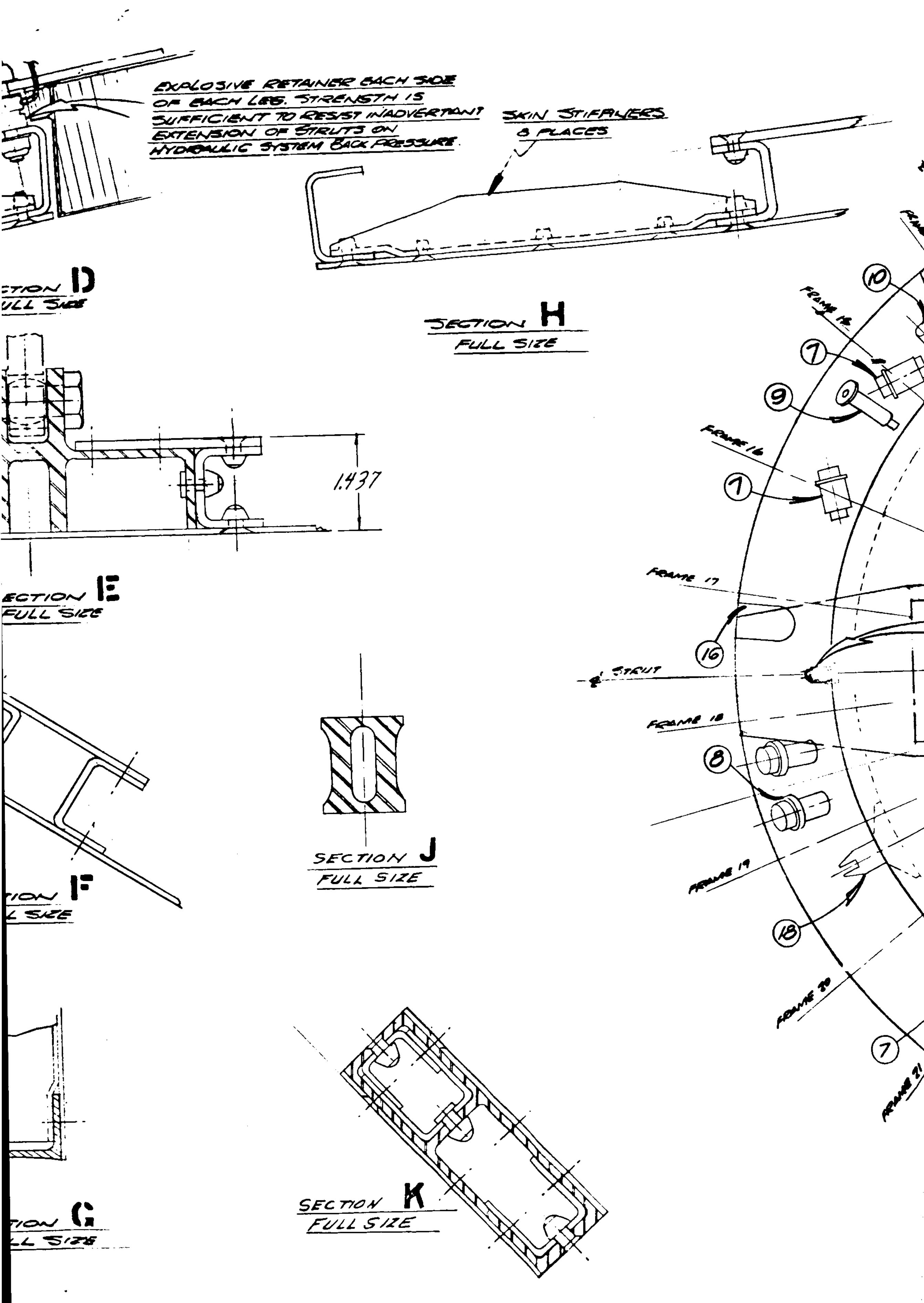

EXPLOSIVE RETAINER EACH SIDE OF EACH LEG. STRENGTH IS SUFFICIENT TO RESIST INADVERTANT EXTENSION OF STRUTS ON HYDRAULIC SYSTEM BACK PRESSURE.
SKIN STIFFENERS 8 PLACES
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SECTION E
FULL SIZE
SECTION J
FULL SIZE
SECTION F
SECTION G
SECTION K
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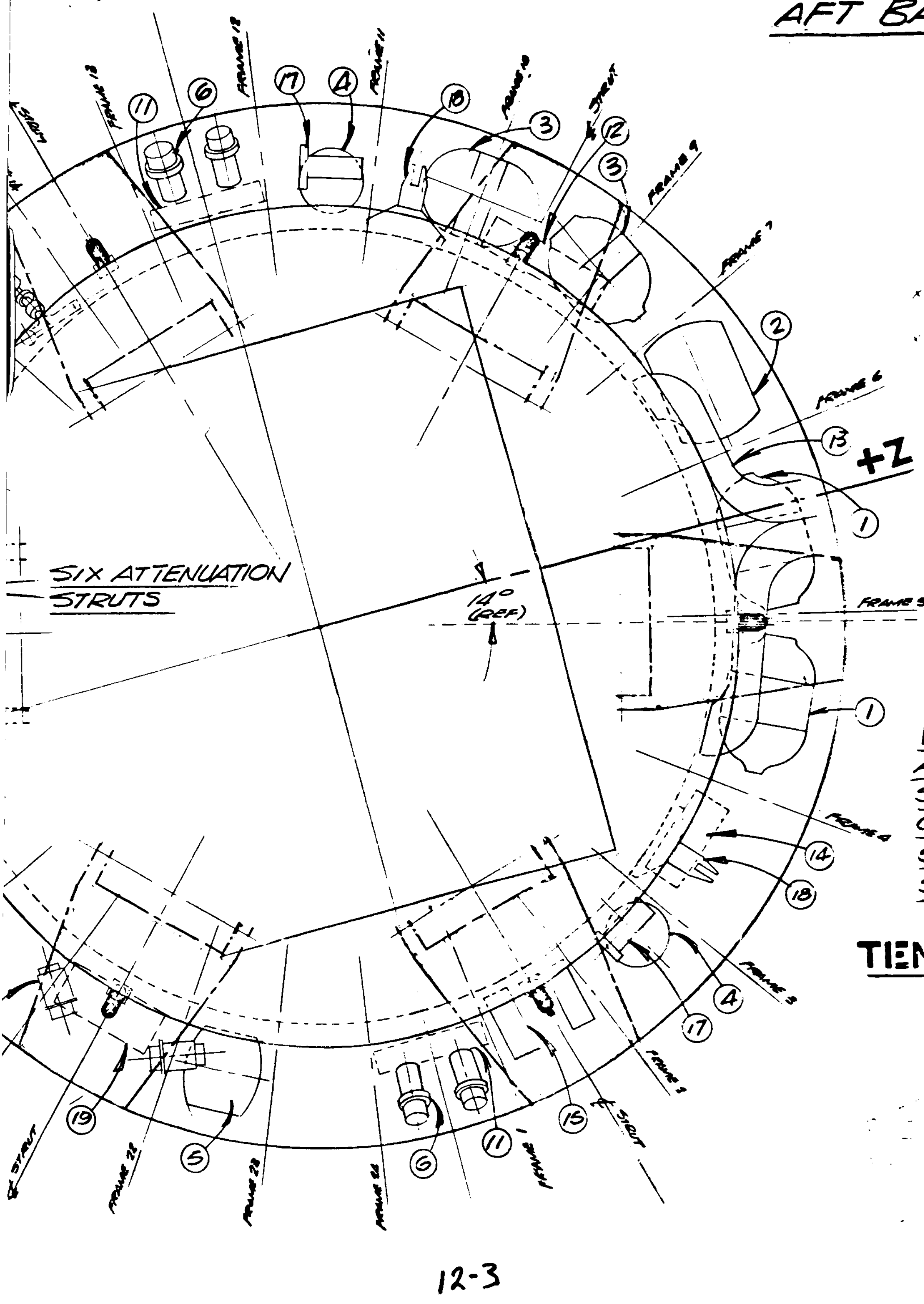

VIEW
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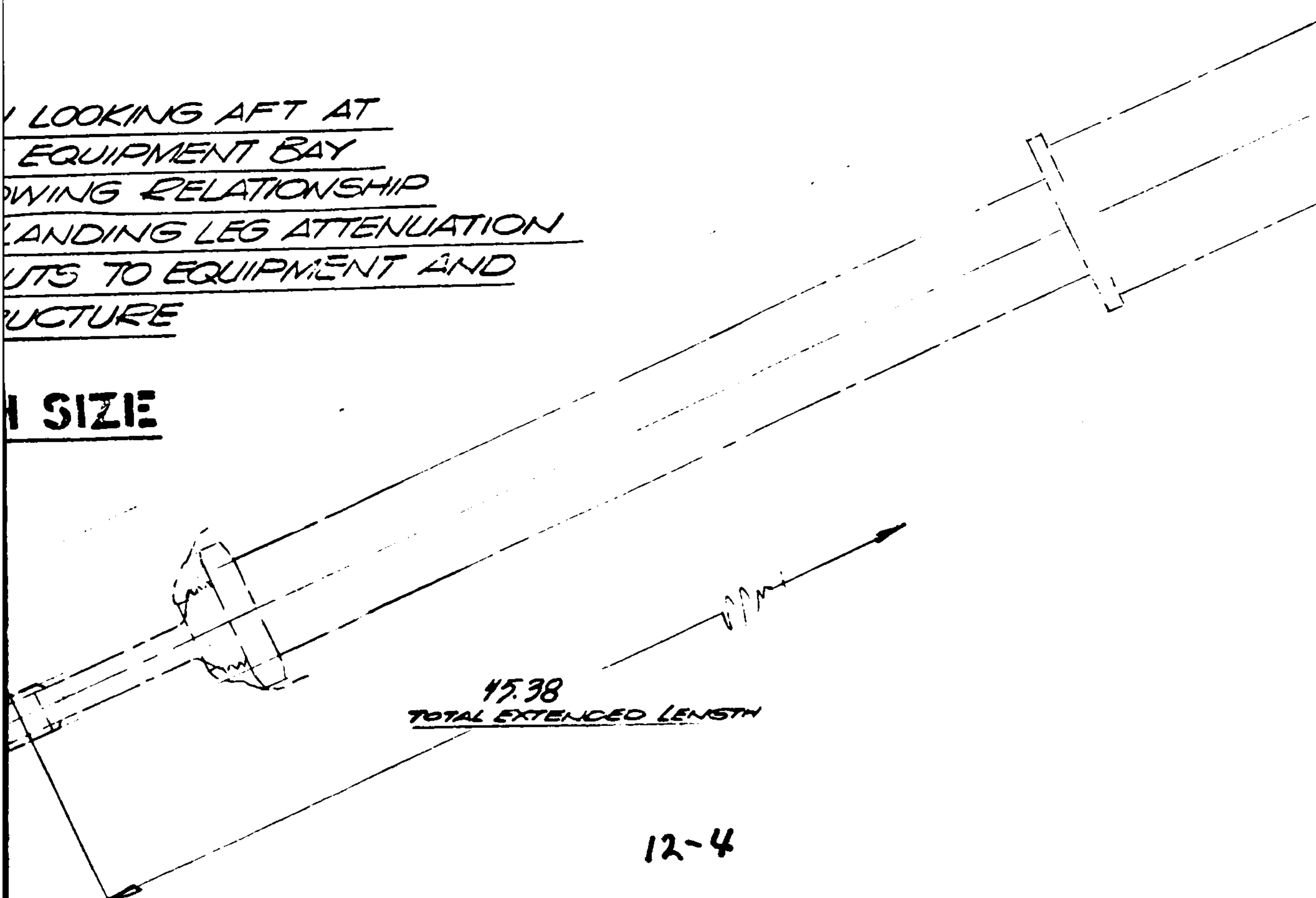
TENTH

FLUENCE ON
EQUIPMENT

M	DESCRIPTION	AFFECTED
	OXIDIZER TANK (2)	NO
	WASTE WATER TANK	NO
	FUEL TANK (2)	NO
	HELIUM TANK (2)	NO
	POTABLE WATER TANK	RELOCATED
	RCS YAW MOTORS (4)	NO
	RCS ROLL MOTORS (4)	NO
	RCS PITCH MOTORS (2)	NO
	RELIEF DUMP NOZZLE	NO
	STEAM VENT	NO
	HELIUM PRESSURE PANEL (2)	NO
2	FUEL CONTROL PANEL	REARRANGED
3	ELECTRICAL UMBILICAL	NO
4	OXIDIZER CONTROL PANEL	NO
5	RCS MOTOR SWITCH (2)	RELOCATED
6	AIR VENT	NO
7	UPRIGHTING SYSTEM COMPRESSOR	NO
8	TENSION TIE	NO
9	RCS CONTROL PANEL	REARRANGED

LOOKING AFT AT
EQUIPMENT BAY
WING RELATIONSHIP
LANDING LEG ATTENUATION
UTS TO EQUIPMENT AND
UCTURE

SIZE



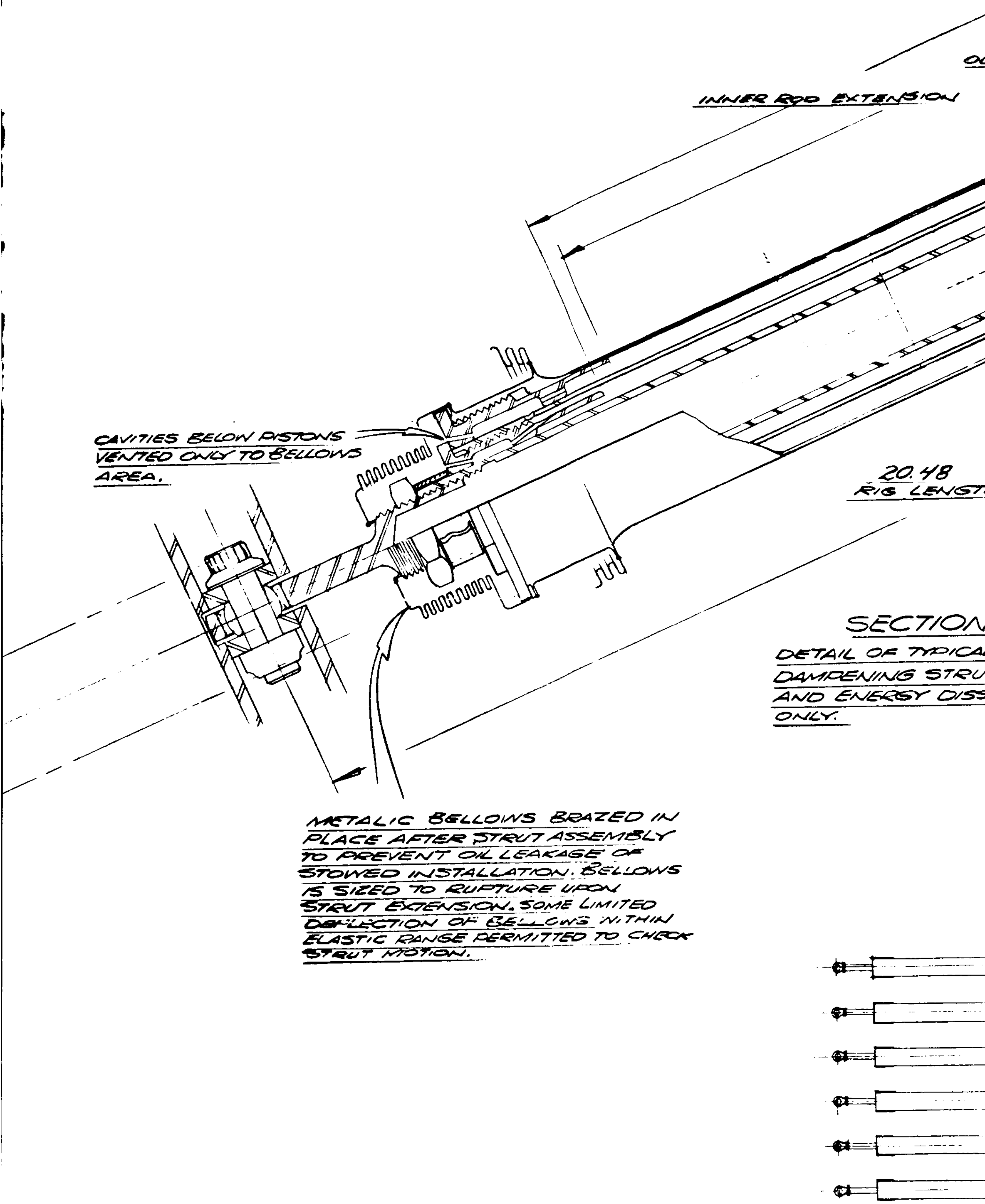

INNER ROD EXTENSION
CAVITIES BELOW PISTONS VENTED ONLY TO BELLOWS AREA.
20.48
RIG LENGT
SECTION
DETAIL OF TYPICA
DAMPENING STRU
AND ENERGY DISS
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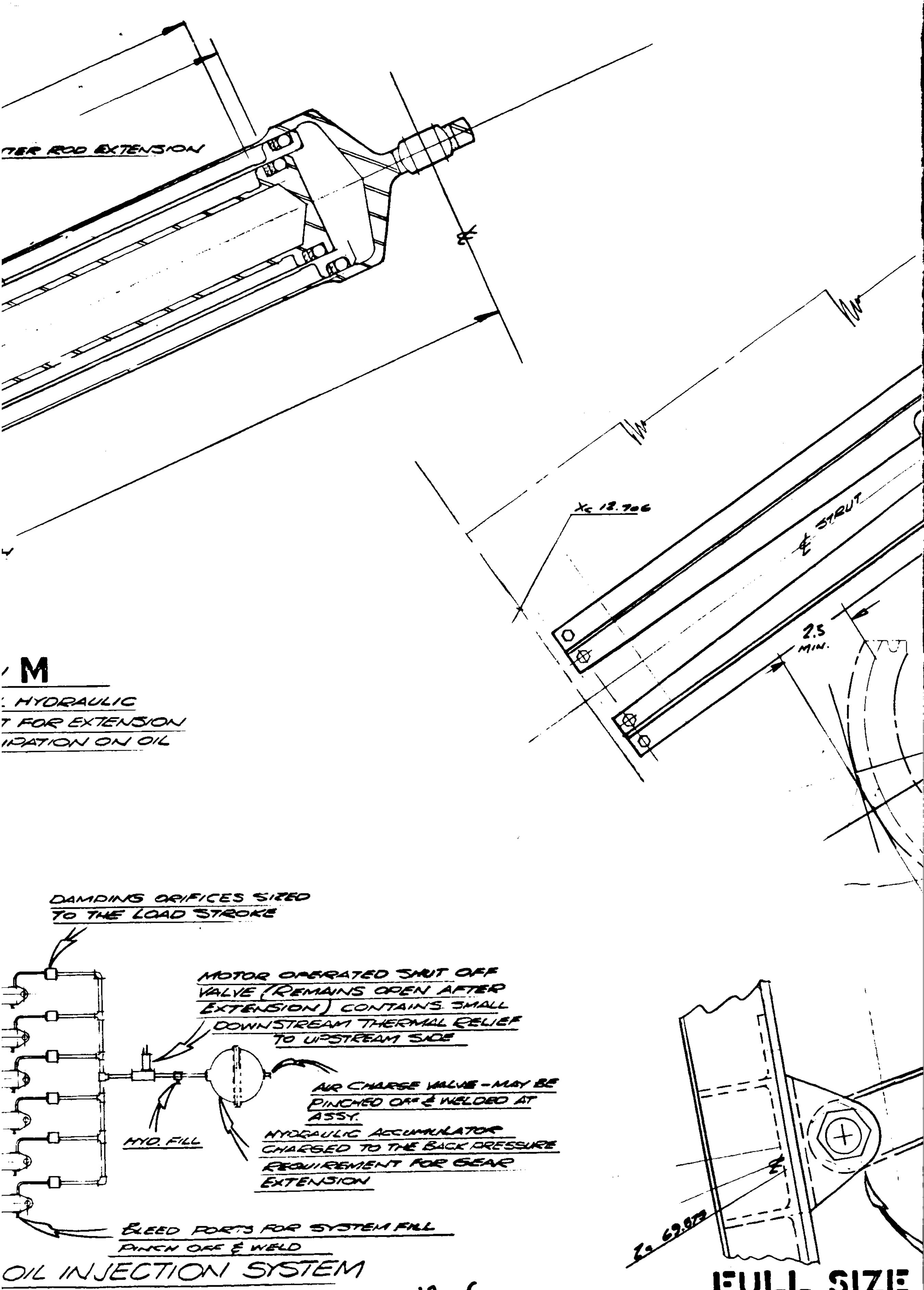
DIAGRAM OF


TER ROD EXTENSION
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IPATION ON OIL
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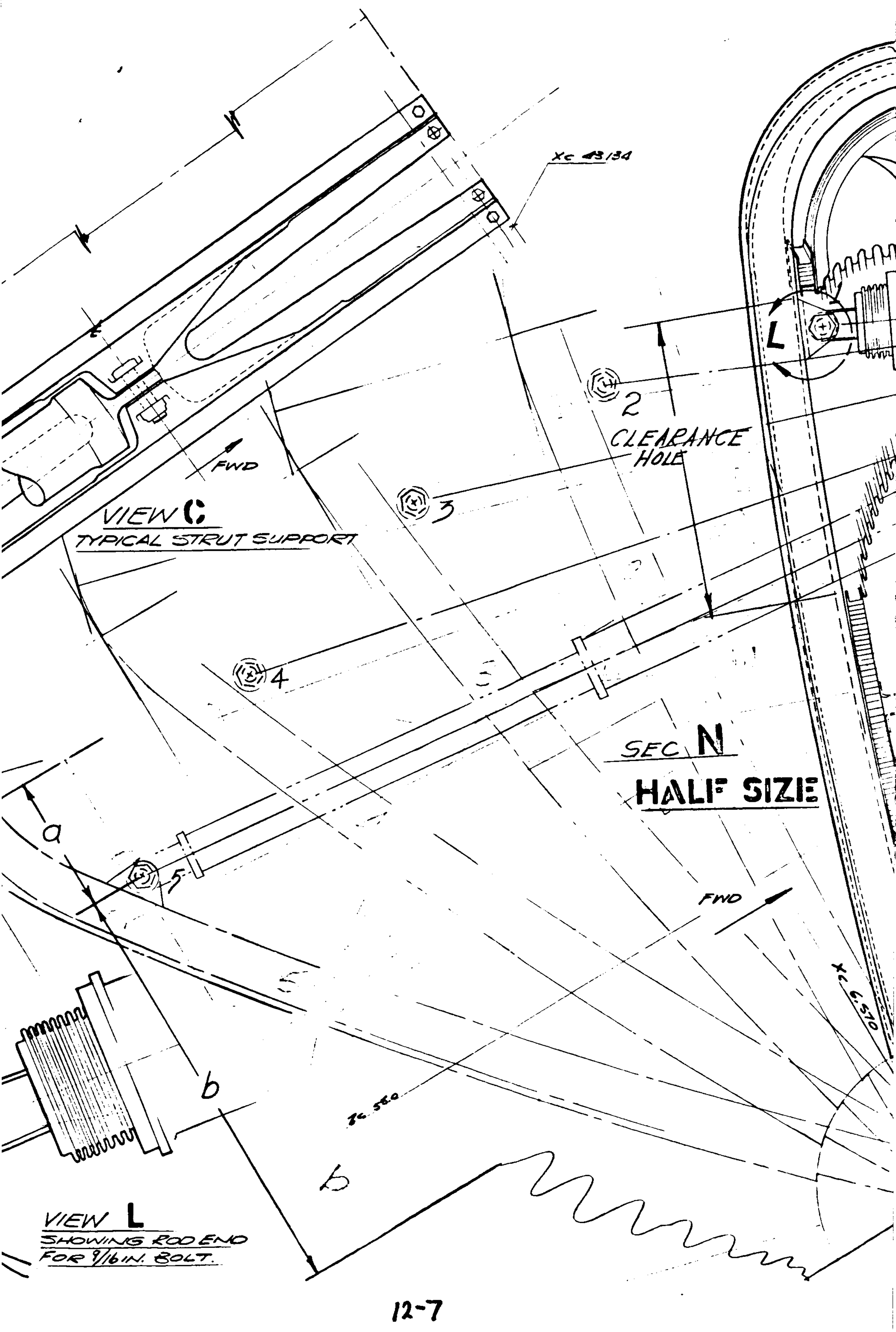
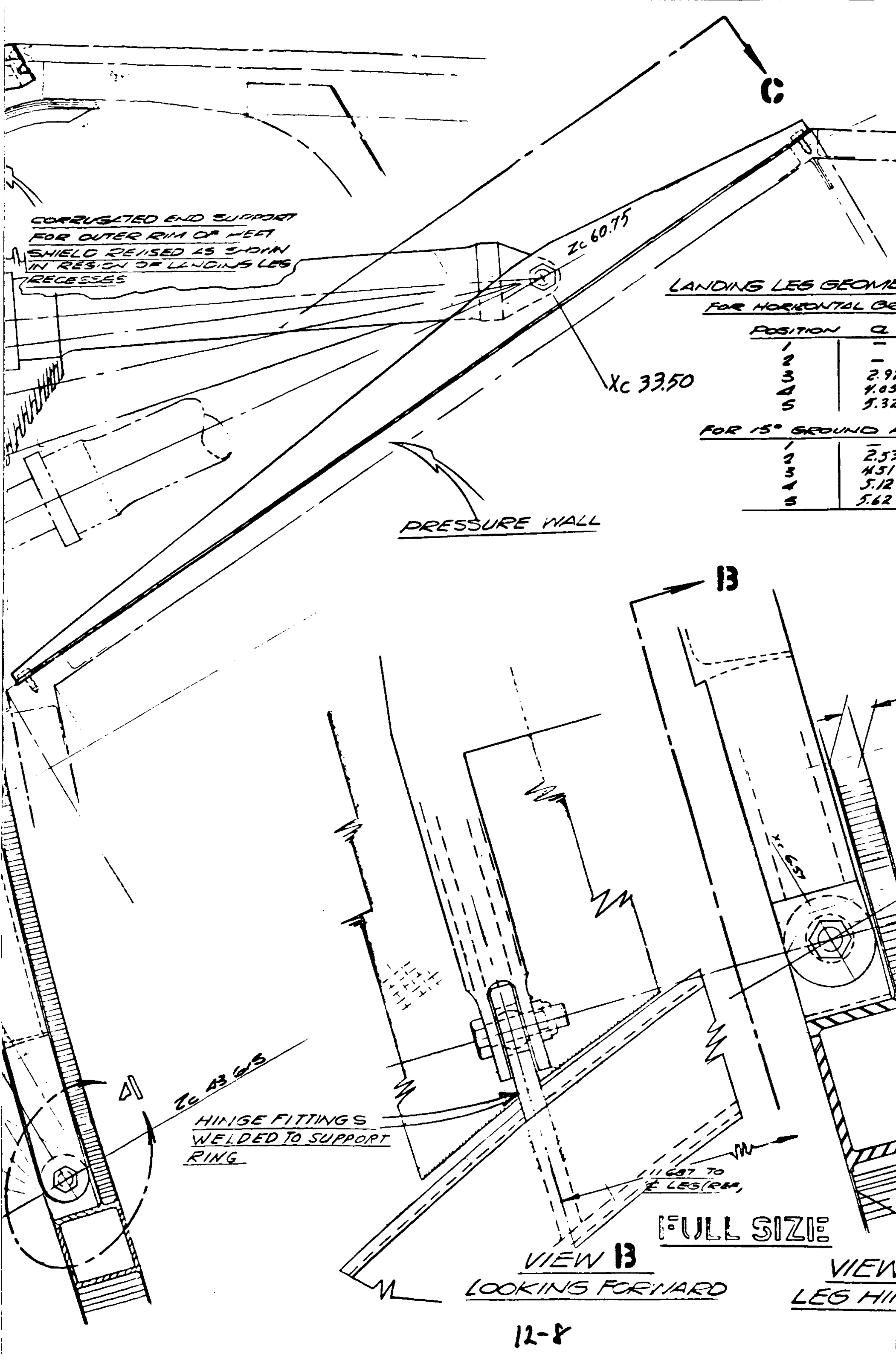
AIR CHARGE VALVE - MAY BE PINCHED OFF & WELDED AT ASSY.
HYD. FILL
HYDRAULIC ACCUMULATOR CHARGED TO THE BACK PRESSURE REQUIREMENT FOR GEAR EXTENSION
BLEED PORTS FOR SYSTEM FILL PINCH OFF & WELD
OIL INJECTION SYSTEM
FULL SIZE



Xc 43.134
2
CLEARANCE HOLE
L
FWD
3
VIEW C
TYPICAL STRUT SUPPORT
4
SEC N
HALF SIZE
a
5
FWD
Xc 6.570
b
Xc 58.0
b
VIEW L
SHOWING ROD END
FOR 9/16 IN. BOLT.


C
CORRUGATED END SUPPORT
FOR OUTER RIM OF HEAT
SHIELD RAISED AS SHOWN
IN REGION OF LANDING LEG
RECESSES
Zc 60.75
Xc 33.50
PRESSURE WALL
B
Zc 43.63
A
HINGE FITTINGS
WELDED TO SUPPORT
RING
FULL SIZE
VIEW B
LOOKING FORWARD
VIEW
LEG HI
LANDING LEG GEOME
FOR HORIZONTAL GR
POSITION
a
1
2
3
4
5
2.92
4.05
5.32
FOR 15° GROUND
1
2
3
4
5
2.53
4.51
5.12
5.62

ETRY

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OUND & DESCENT			
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	26.82	16	33.85
	24.26	10	40.12
	20.26	3.5	45.38
NGLE LANDING			
	—	11	
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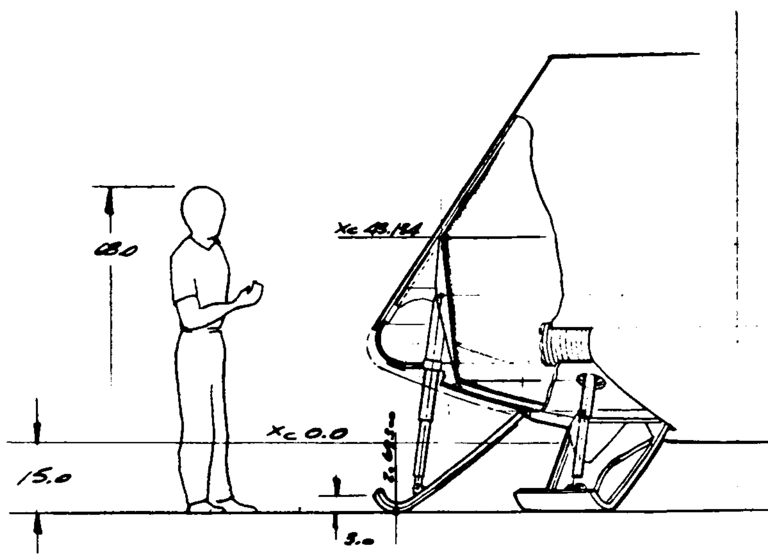
	24.55	2	
	20.42	4.5	
	15.05	10.5	



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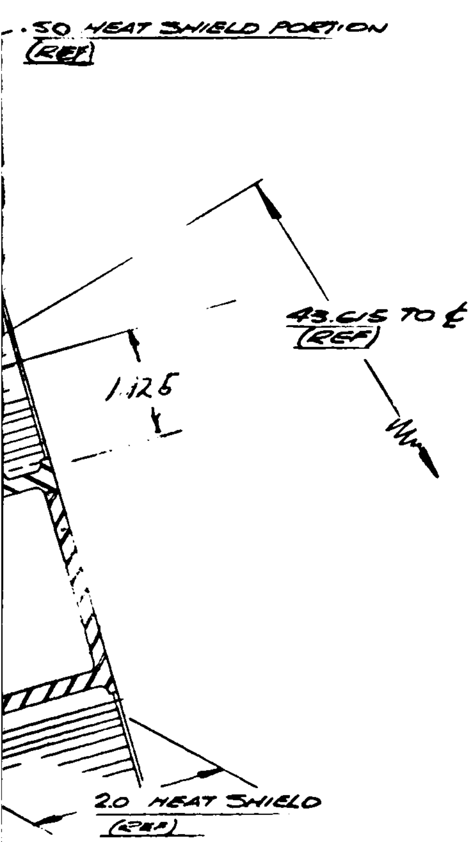

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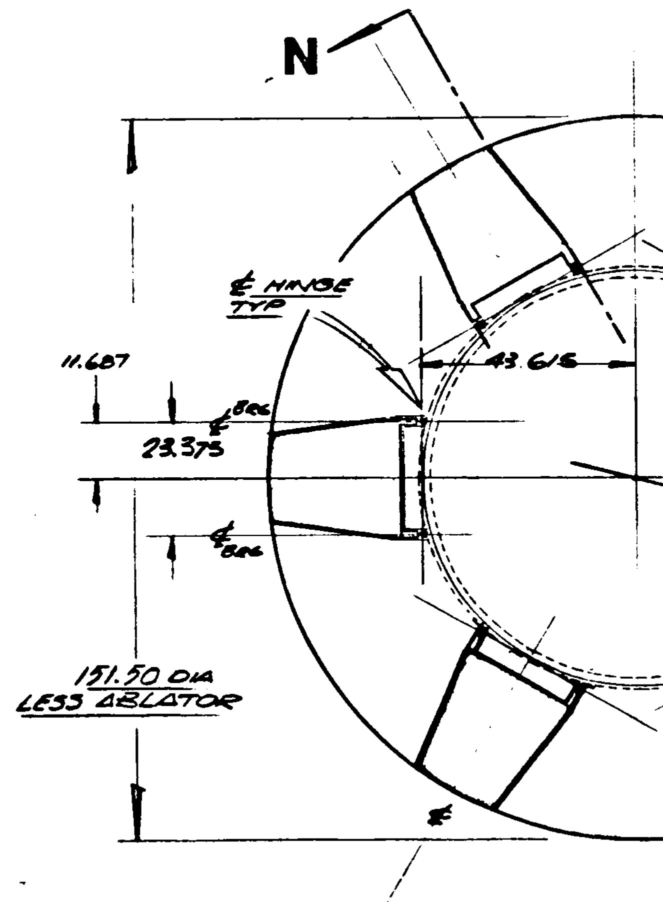


VIEW LOOKING

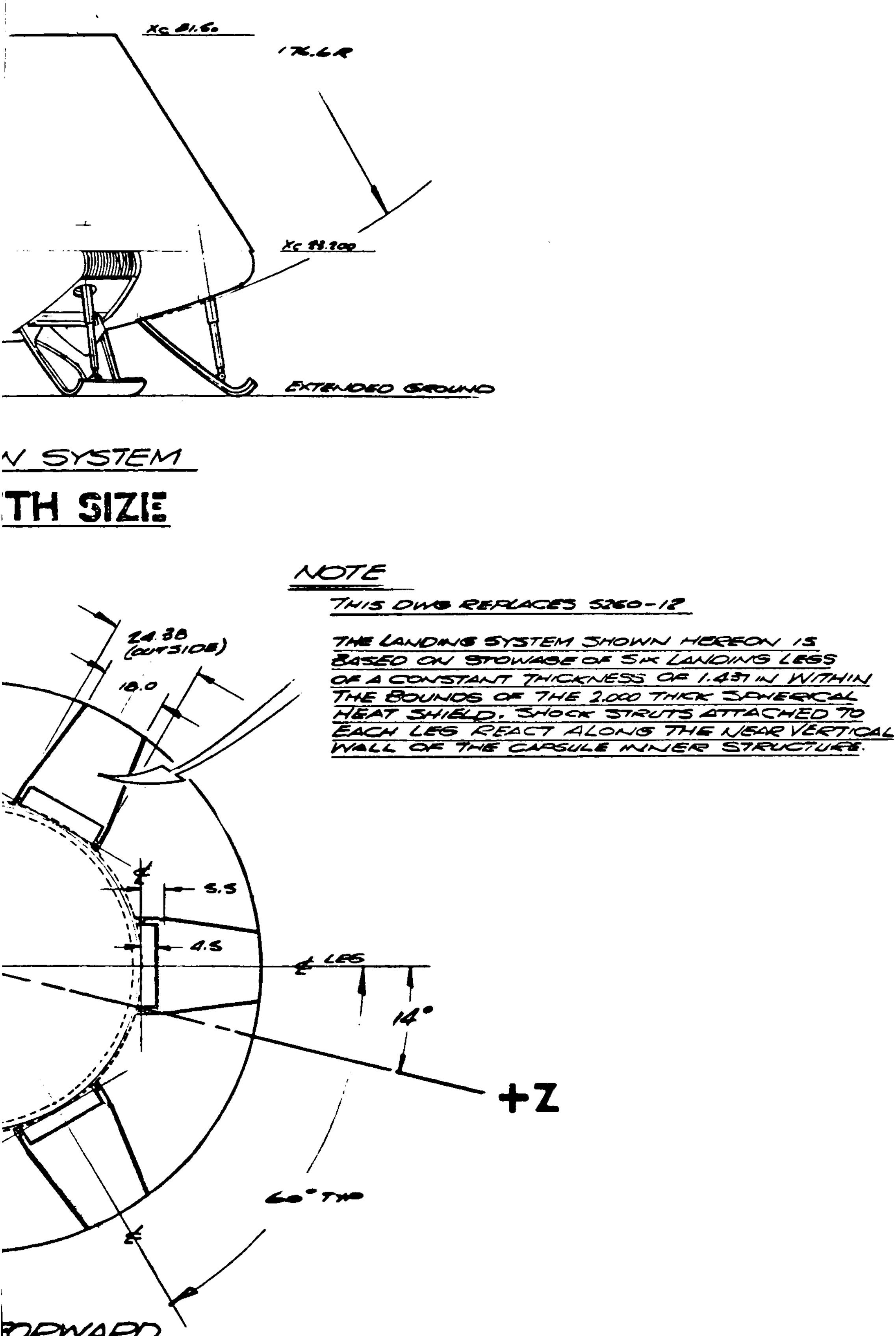
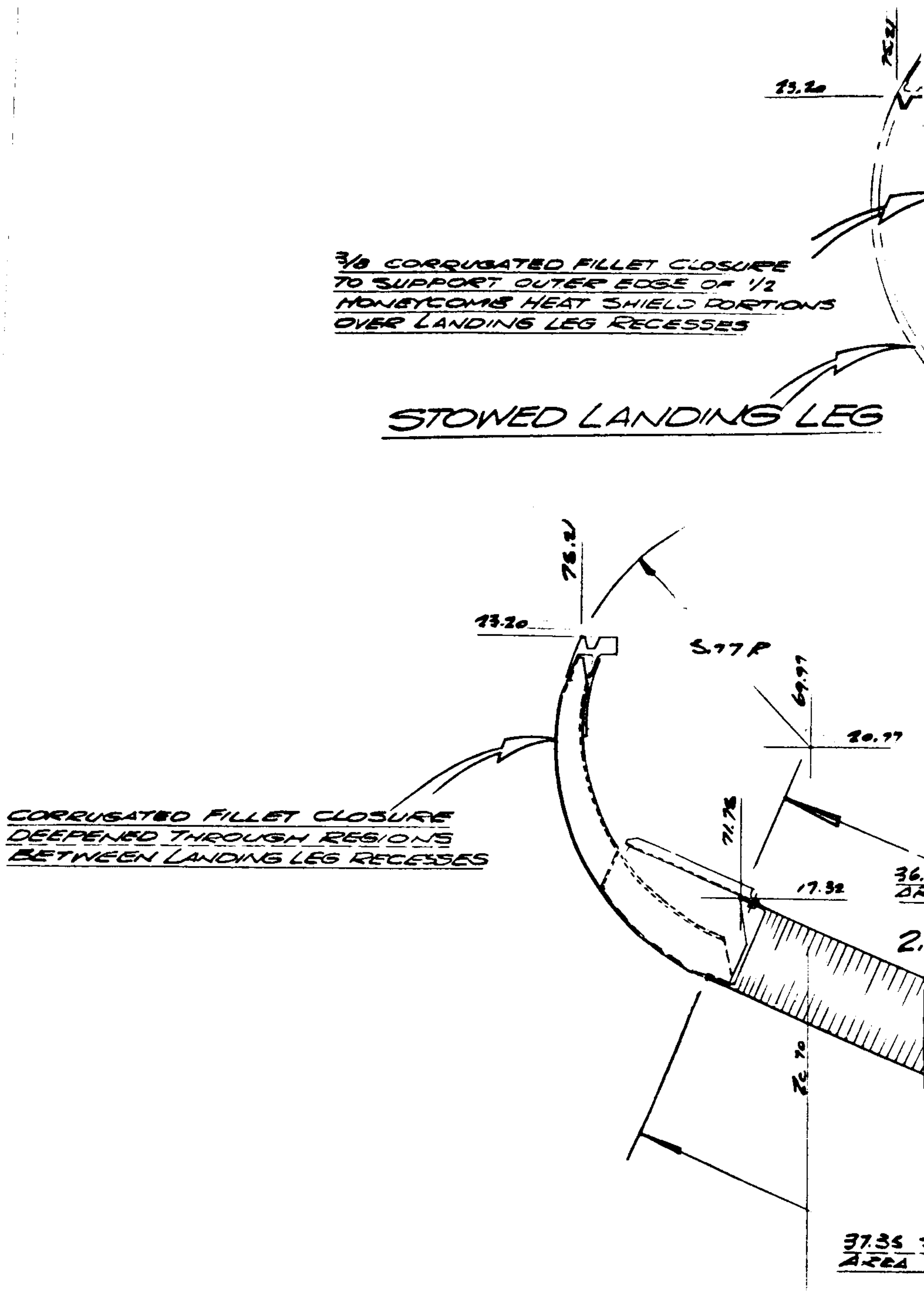


Figure 4. Six-Radial-Leg Landing System - MISDAS Study



SECTION THRO
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LEGS

HALF

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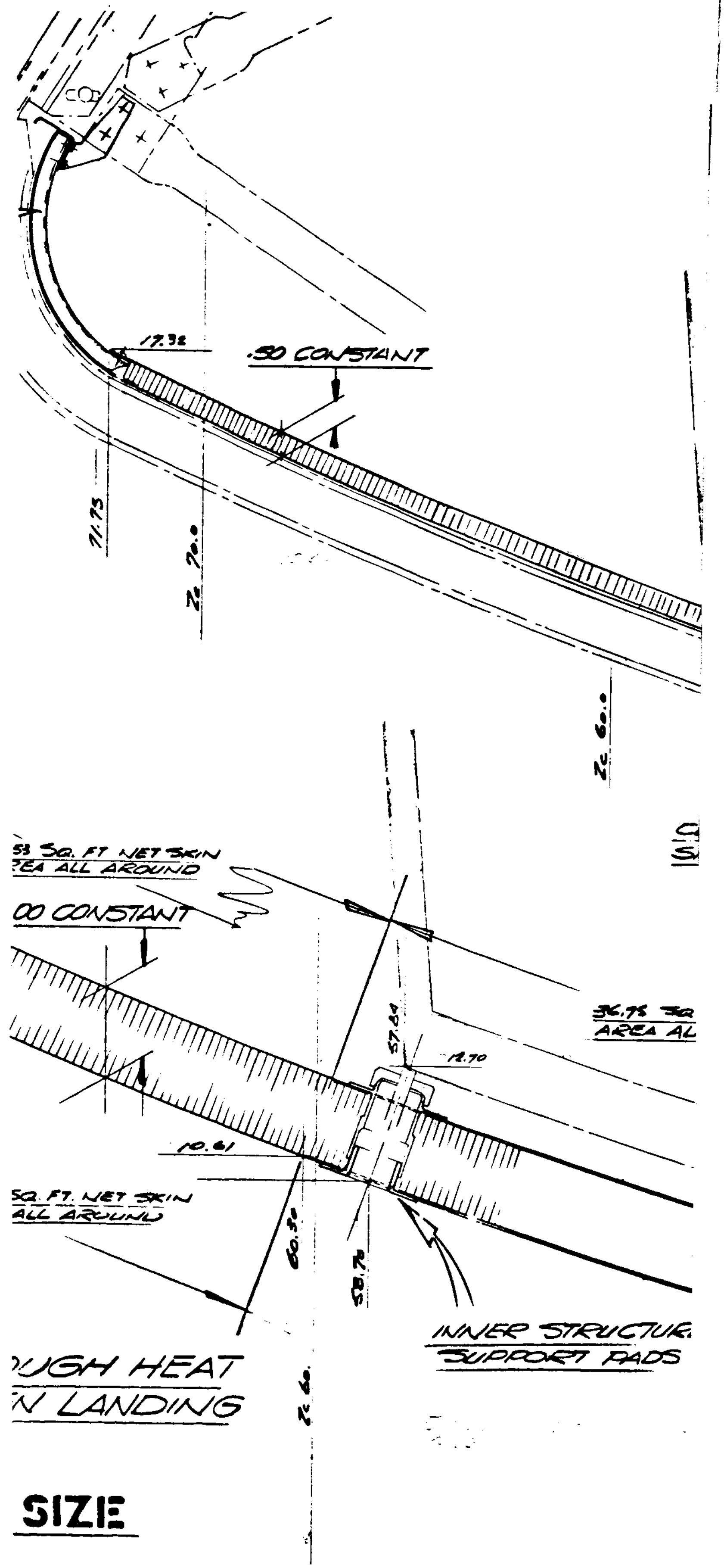
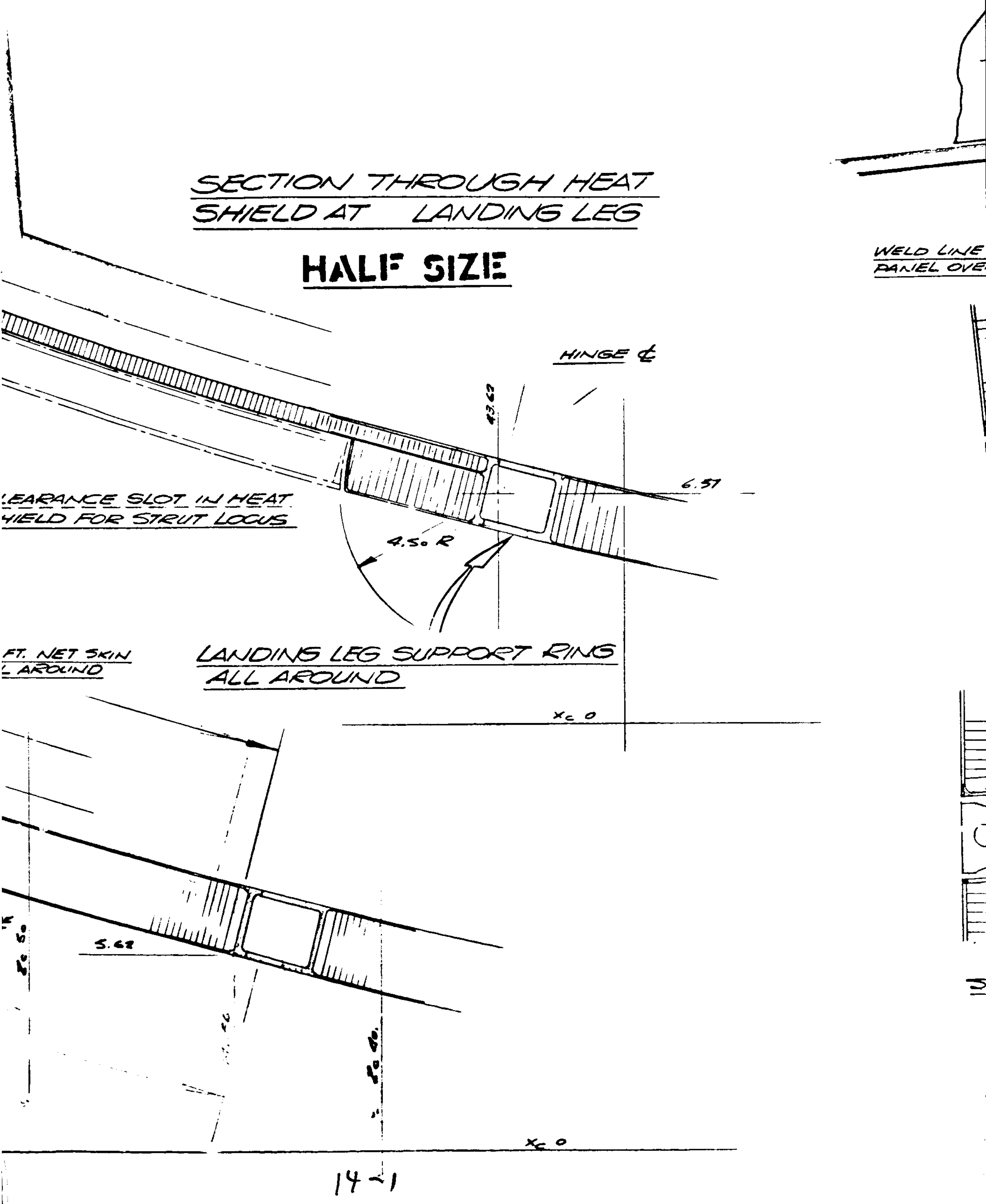
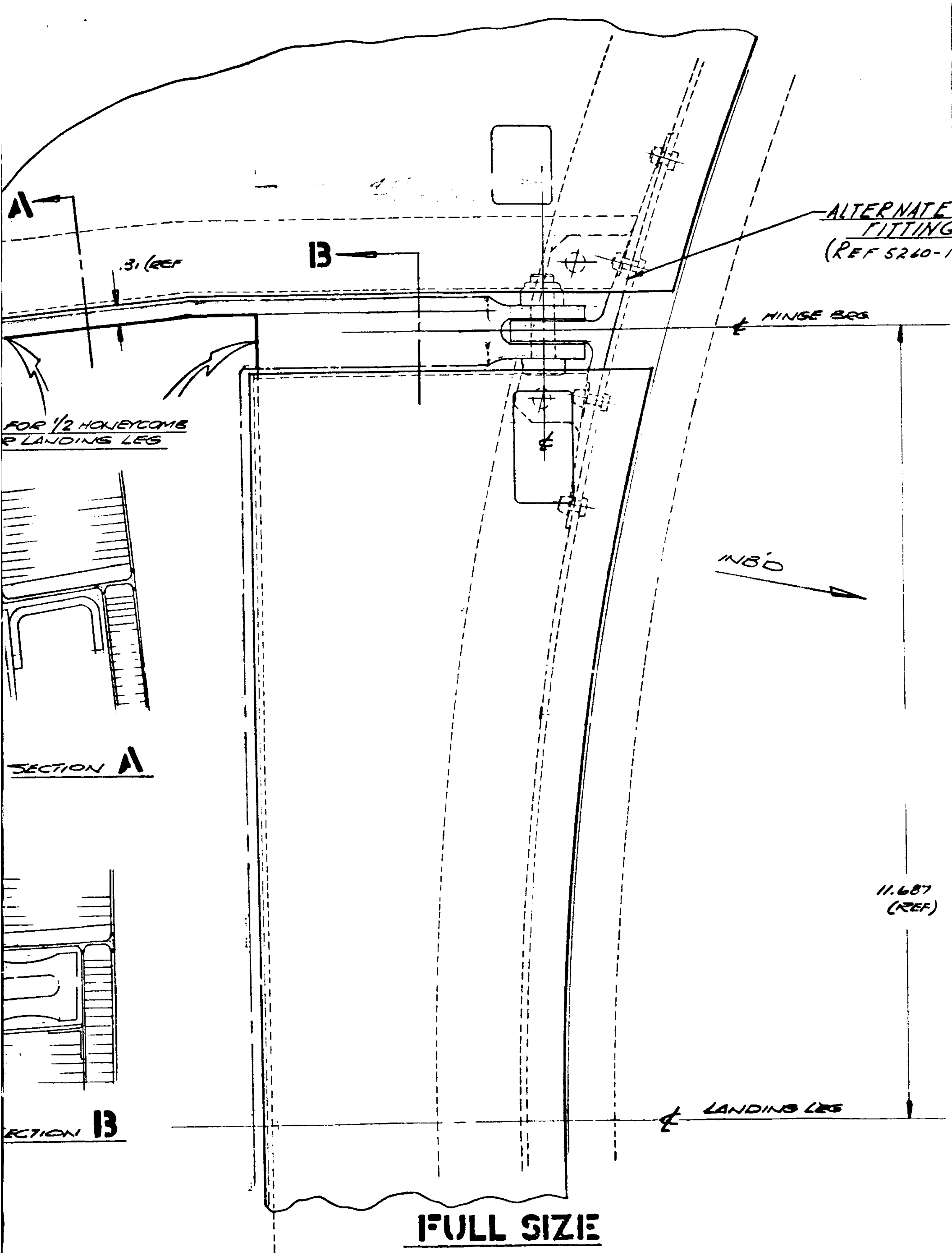

17.32
.50 CONSTANT
71.75
Zc 70.0
Zc 60.0
53 SQ. FT NET SKIN
EA ALL AROUND
00 CONSTANT
36.75 SQ
AREA AL
57.84
12.70
10.61
SQ. FT. NET SKIN
ALL AROUND
60.30
58.70
INNER STRUCTUR
SUPPORT PADS
UGH HEAT
N LANDING
Zc 60.
SIZE

13 (2)


SECTION THROUGH HEAT SHIELD AT LANDING LEG
HALF SIZE
HINGE ¢
43.69
6.57
LEARANCE SLOT IN HEAT
HIELD FOR STRUT LOCUS
4.50 R
FT. NET SKIN
AROUND
LANDING LEG SUPPORT RING ALL AROUND
5.68
WELD LINE
PANEL OVE

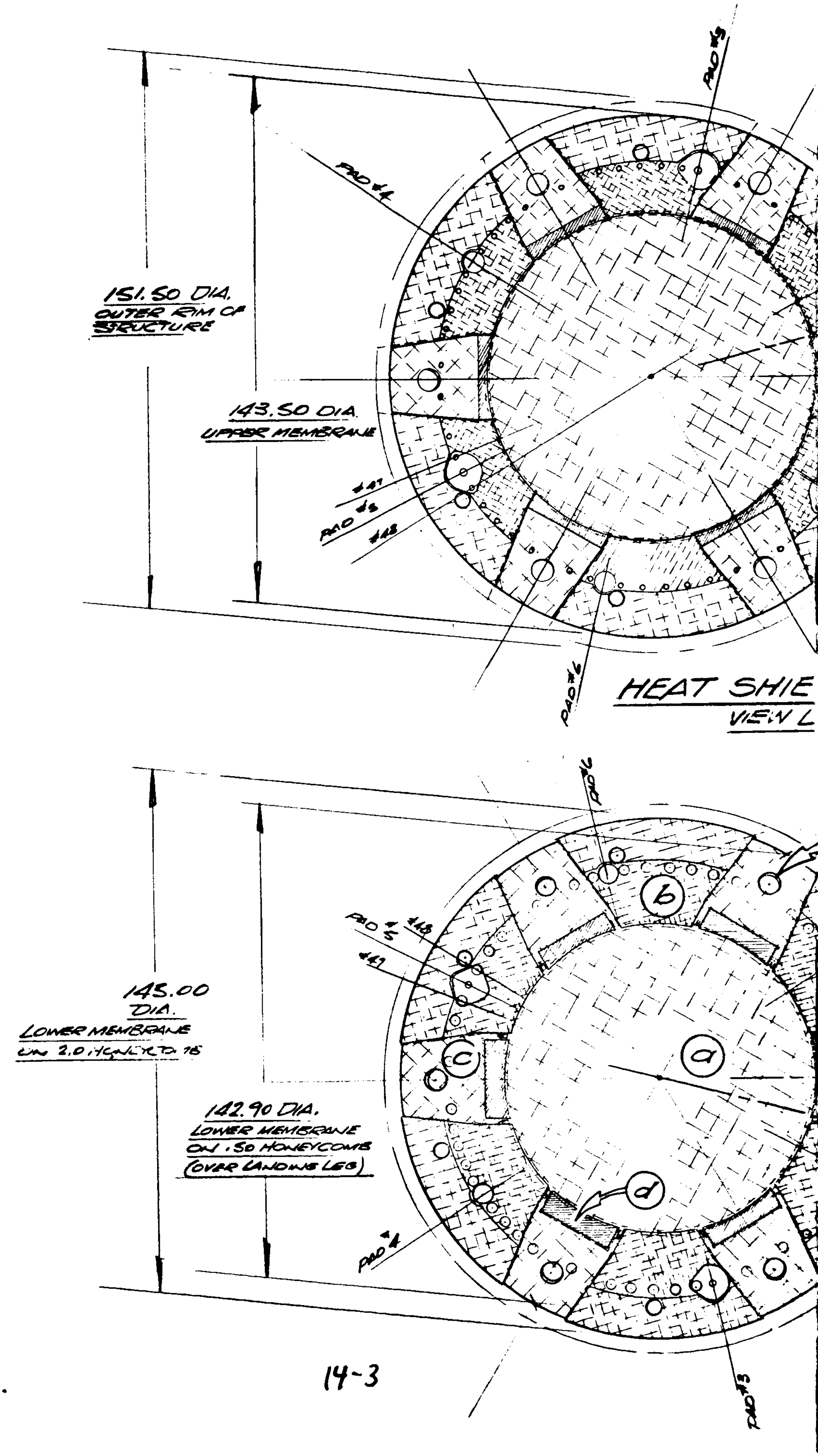


VIEW LOOKING FORWARD AT LANDING LEG HINGE

14-2

NOR

HINGE


151.50 DIA.
OUTER RIM OF STRUCTURE
143.50 DIA.
UPPER MEMBRANE
PAD #4
PAD #3
PAD #5
#47
#48
PAD #6
HEAT SHIE
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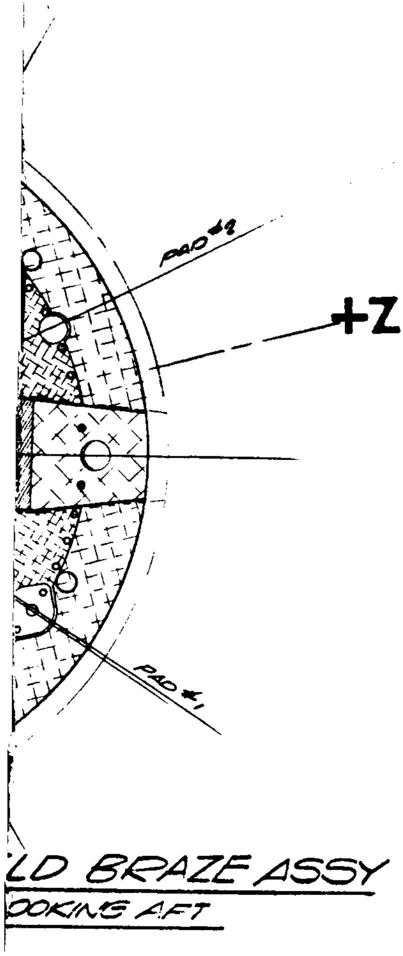
145.00 DIA.
LOWER MEMBRANE ON 2.0 HONEYCOMB
142.90 DIA.
LOWER MEMBRANE ON .50 HONEYCOMB (OVER LANDING LEG)
a
b
c
d



HONEYCOMB AREAS

PORTION	DESCRIPTION	NOM. AREA
a	CIRCULAR CENTER PORTION OF 2.0 THICK HONEYCOMB SANDWICH.	40.0 FT²
b	SIX CIRCULAR SECTORS OF 2.0 HONEYCOMB SANDWICH FROM RING TO ℄ INCLUDING PATTERN OF SUPPORTS.	19.0 FT²
c	SIX PANELS OF 0.50 HONEYCOMB SANDWICH OVER LANDING LEG STOWAGE RECESSES	29.1 FT²
d	SIX FILL PORTIONS OF 1.5 HONEYCOMB SANDWICH FROM RING OUTWARD TO LANDING LEG INBOARD CLOSURE	4.4 FT²
e	SIX CIRCULAR SECTORS OUTBOARD OF PATTERN OF SUPPORTS & BETWEEN LANDING LEG RECESSES	27.0 FT²

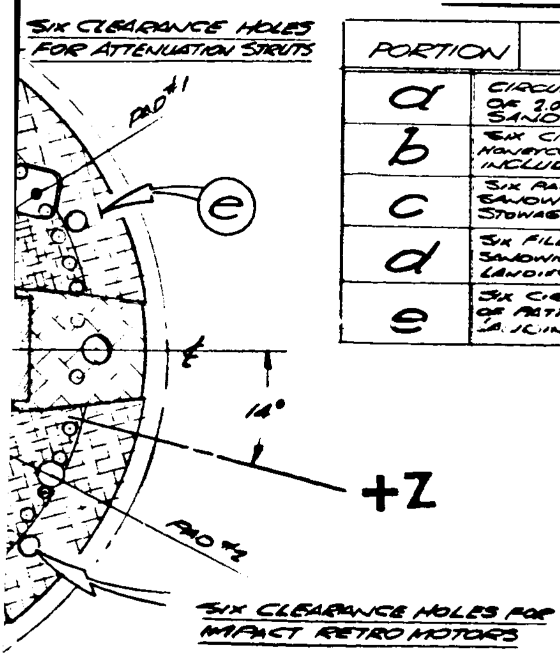


Figure 5. Aft Compartment Heat Shield for Use With Six-Leg Landing System

as they compress in landing. The actual oil displaced in attenuation is that which was previously introduced to the struts to extend the legs in preparation for landing.

The struts operate in a duty length from 20.50 inches retracted to 45.38 inches extended, and derive their 24.88-inch operational range from two coaxial rods and pistons. Each strut is provided with a bleed line located above the pistons that may be pinched off and welded at the conclusion of fill and bleed of the system. Hydraulic oil is filled throughout the system, but only above the pistons and in the retracted configuration. Cavities in the cylinder below the pistons contain no oil, and are, therefore, vented externally to permit cylinder cavity evacuation as the struts are extended. The unsealed end of the strut is equipped with a brazed bellows closure that safeguards against inadvertent oil leakage past the piston seals. The bellows should deflect sufficiently to permit limited stroking of the struts in system checkout, be of sufficient strength to resist an internal atmosphere in the vacuum environment, and be readily fractured by the force of rod extension.

The cylindrical body of each strut is provided with a conical bellows brazed to it and to the heat shield over the recess through which the rods operate. When installed, the bellows form sealed closures at each clearance hole to prevent flow of the hot gas from the landing retromotors to the inner structure of the spacecraft.

Ablative Heat Shield

The aft heat shield ablative material and thickness distribution can be the same as for the basic AES vehicle. Gaps in the heat shield ablator made necessary by the extendable landing legs are filled with gasket material conforming to the currently recommended silicone synthetic compounded to the Apollo specification (Reference 6). Portions of the ablator over the legs are bonded to them in precise shapes that present faying edges geometrically shaped to match the extending motion with minimum bind and interference. To achieve this, each gap in the ablator possesses a wall normal to the surface on the fixed side, and a sloped wall on the movable side so the legs can be withdrawn from the stowed position at an angle open to the motion, thus, minimizing scrubbing.

The inboard center portion of the landing leg segments, a length of about 22 inches, has a face which is a surface of revolution about the leg

hinge center line, except for a slight draft to aid the leg motion. The nominal radius of the surface is 4.5 inches, which is considered a reasonable minimum to avoid a feather edge on the external surface of the ablator panel on the leg. The requirement to rotate the inboard side of the landing legs 4.5 inches from the hinge center line leaves narrow arms of 4.5 inches on each side as supports from the two hinges. The hinge arms have been provided with ablator plugs sloped to jettison from the vehicle as the force of the landing leg extension fractures their attachment. These details are shown in Section C of Figure 5.

System Operation

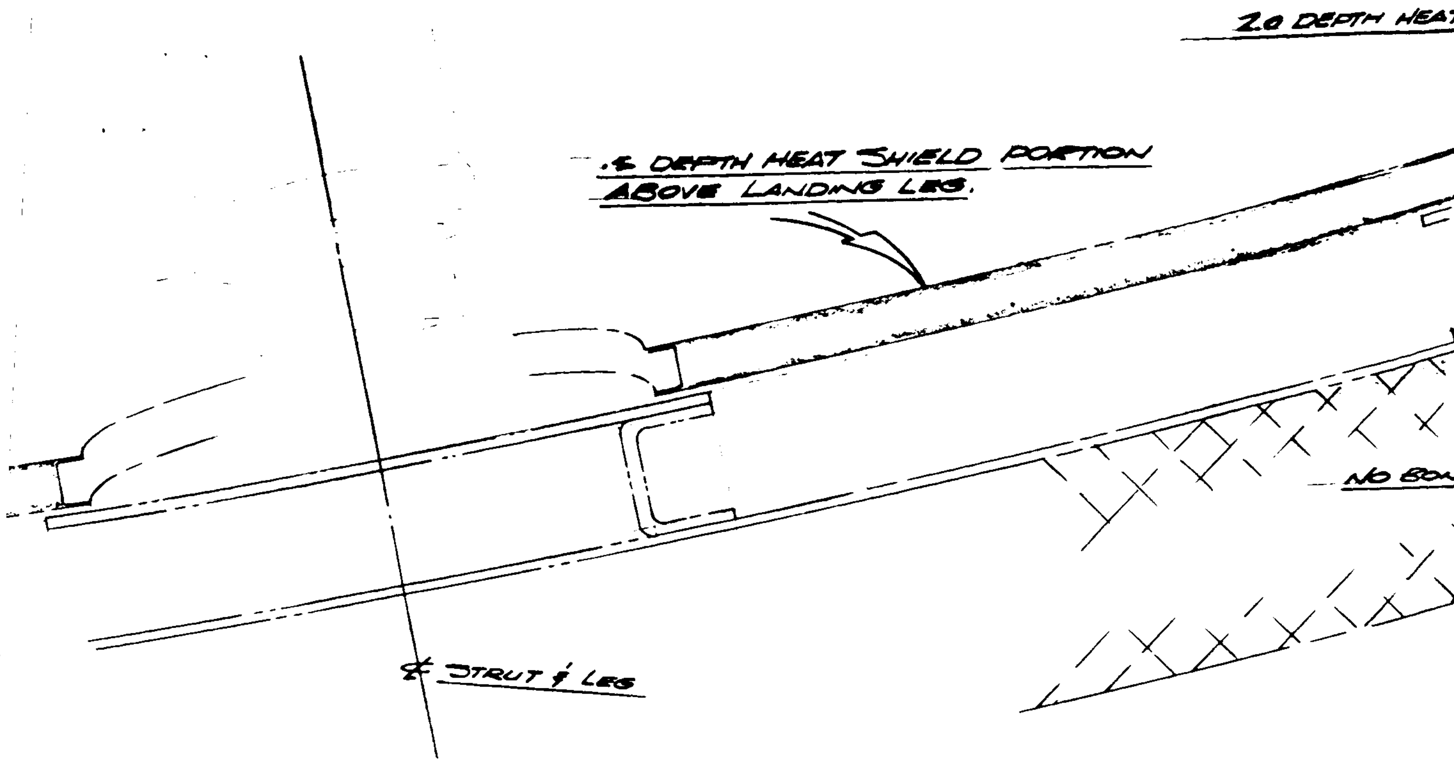
Deployment of the landing impact system starts with a landing signal emitted by an altitude sensing system. This signal is followed by actuation of the explosive bolts which retain the legs and introduction of pressure into the struts by a two-way valve. The resultant force in the struts opens the landing legs from the fixed heat shield and extends them to the landing position. Landing energy is spent by ejection of the pressurized oil from the compressed struts. Landing loads are transmitted to the command module inner structure through strut attachments on the side wall and through the leg hinges that connect to the fixed portion of the heat shield.

Spacecraft Compatibility

The command module inner structure will require modifications to accommodate the landing impact system attachments. The specific requirements for relocation of equipment to install and operate the landing impact system are discussed on page 19 under Packaging Considerations. The design of the aft heat shield was modified to incorporate the legged segments within the contours of the AES command module. Technical problems derived from manufacturing and operation of this heat shield have been studied and feasible solutions are presented in Figure 6.

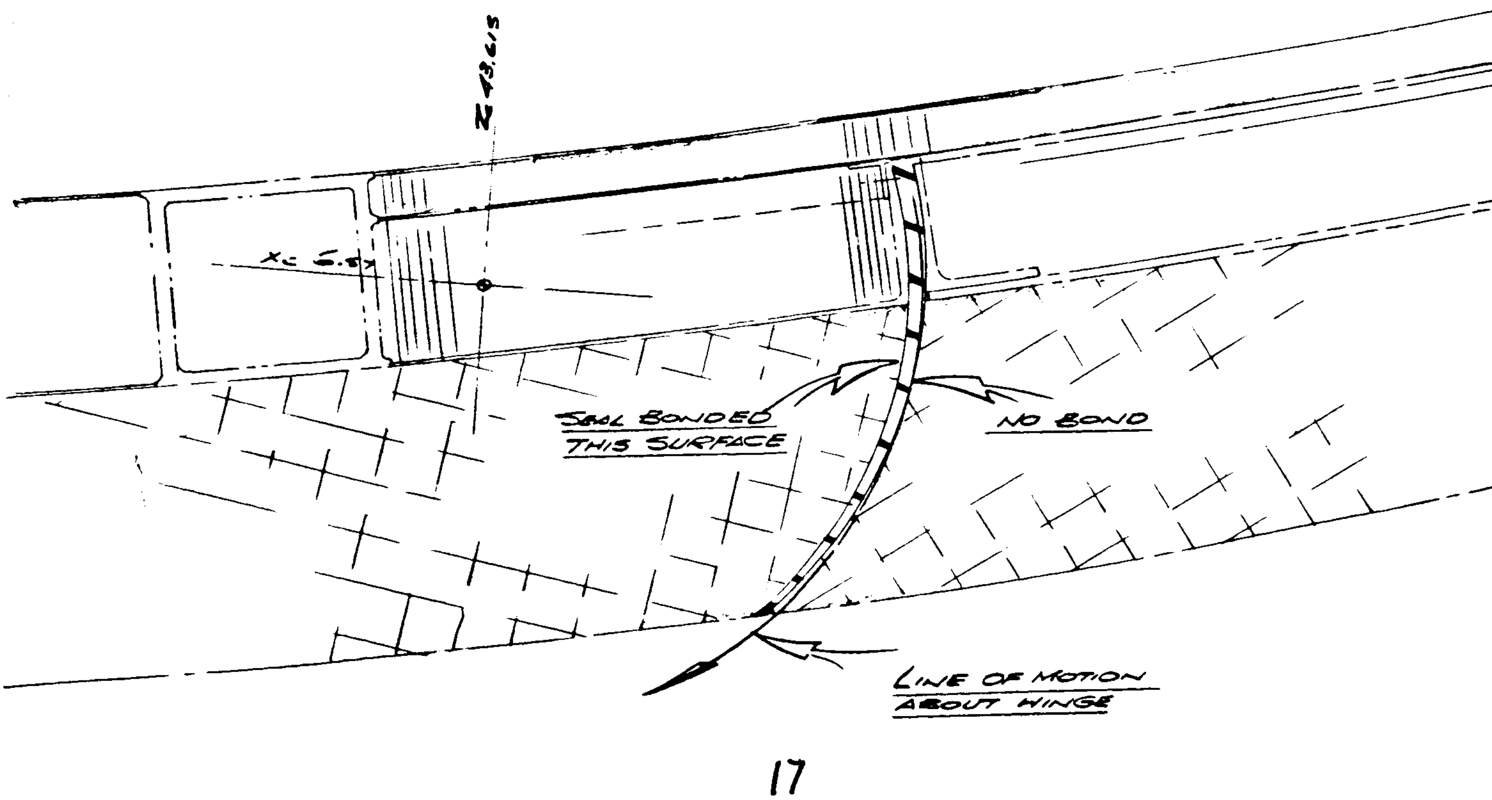
MISDAS/AES/RETROROCKET INTEGRATION

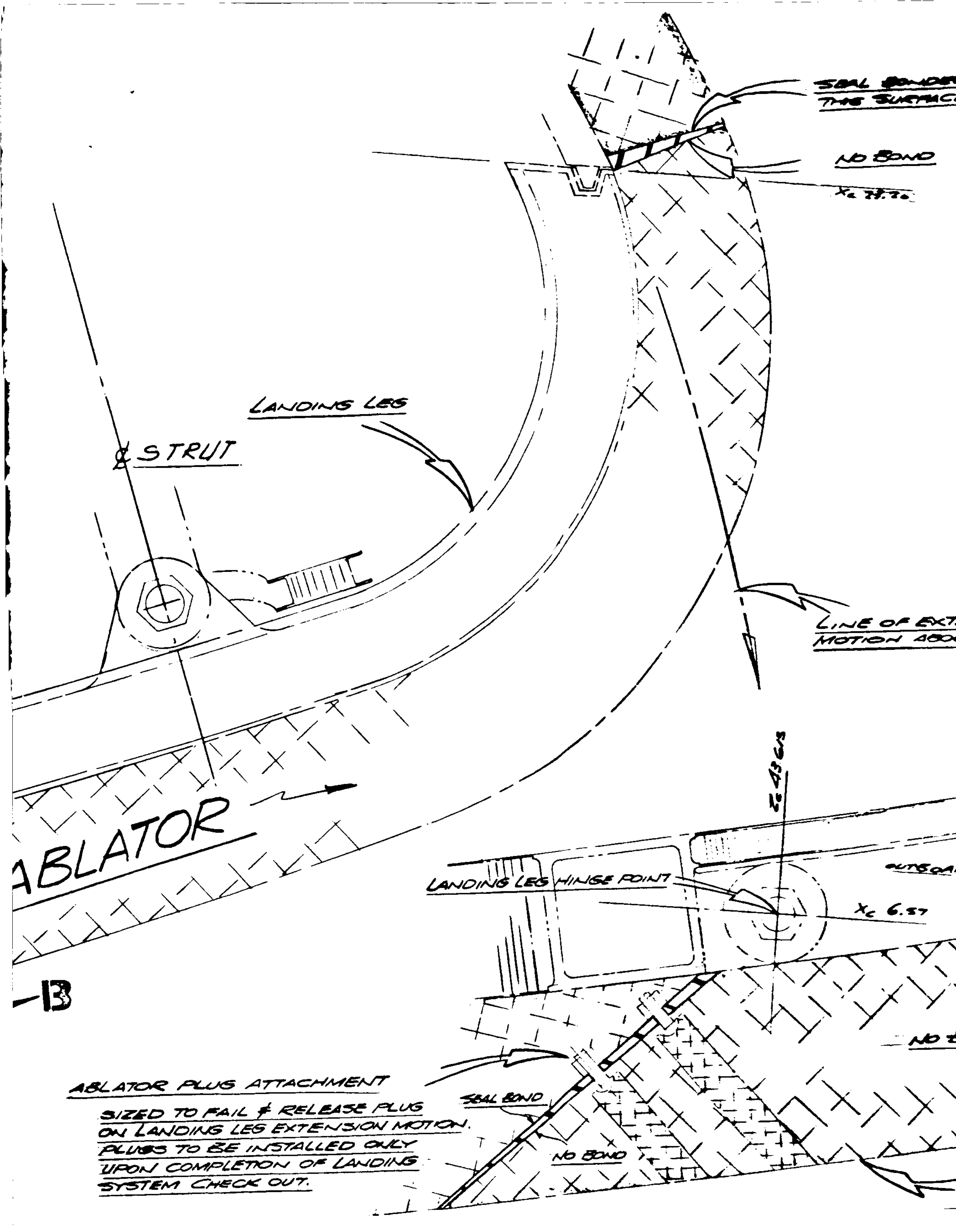
For the MISDAS/AES application study, a design concept using four modified Gemini retromotors, selected by NASA for AES, is utilized for vertical descent retardation.



SECTION B THROUGH LANDING LEG
SHOWING SIDE BOUNDARY SEAL

FULL





SECTION C THROUGH LANDING LEG HIN
SHOWING ABLATIVE PLUG FOR DISPLAC
AND SEAL ARRANGEMENT

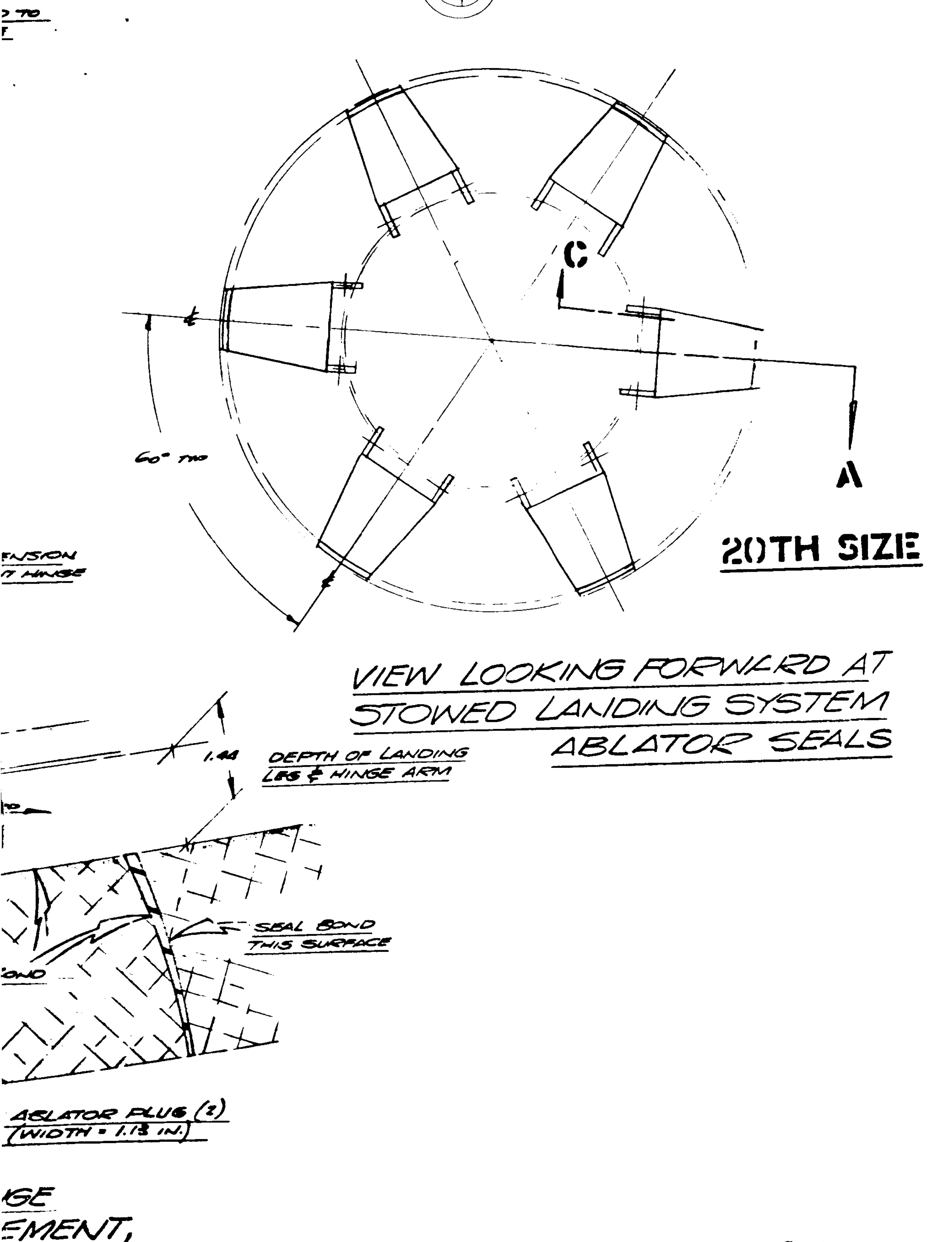


Figure 6. Ablator Seal Arrangement - Six-Leg Landing System, MISDAS Study

The basic motor configuration was used as designed and structurally mounted for the AES spacecraft although the nozzle was changed. The configuration of the ejectable plug in the heat shield used to provide an opening for retromotor exhaust gas was developed for AES.

In no case does the relocation of equipment introduce any significant thermal problem. Effects on the spacecraft center of gravity and inertia are included in the analysis summarized in Table 8. The effect on stability in flight and landing conditions was neglibile.

Packaging Considerations

The concept shown in Figure 7 illustrates a gross packaging arrangement for the four retromotors, the subsystem components, and six deployable heat shield segments. The structural and mechanical details of the segmented heat shield concept are shown in Figure 4. The six segments are symmetrically located in the heat shield with the axis of the pattern positioned 14 degrees off the command module +Zc axis. The retromotors are unsymmetrically positioned 30 and 40 degrees either side of the command module -Zc axis.

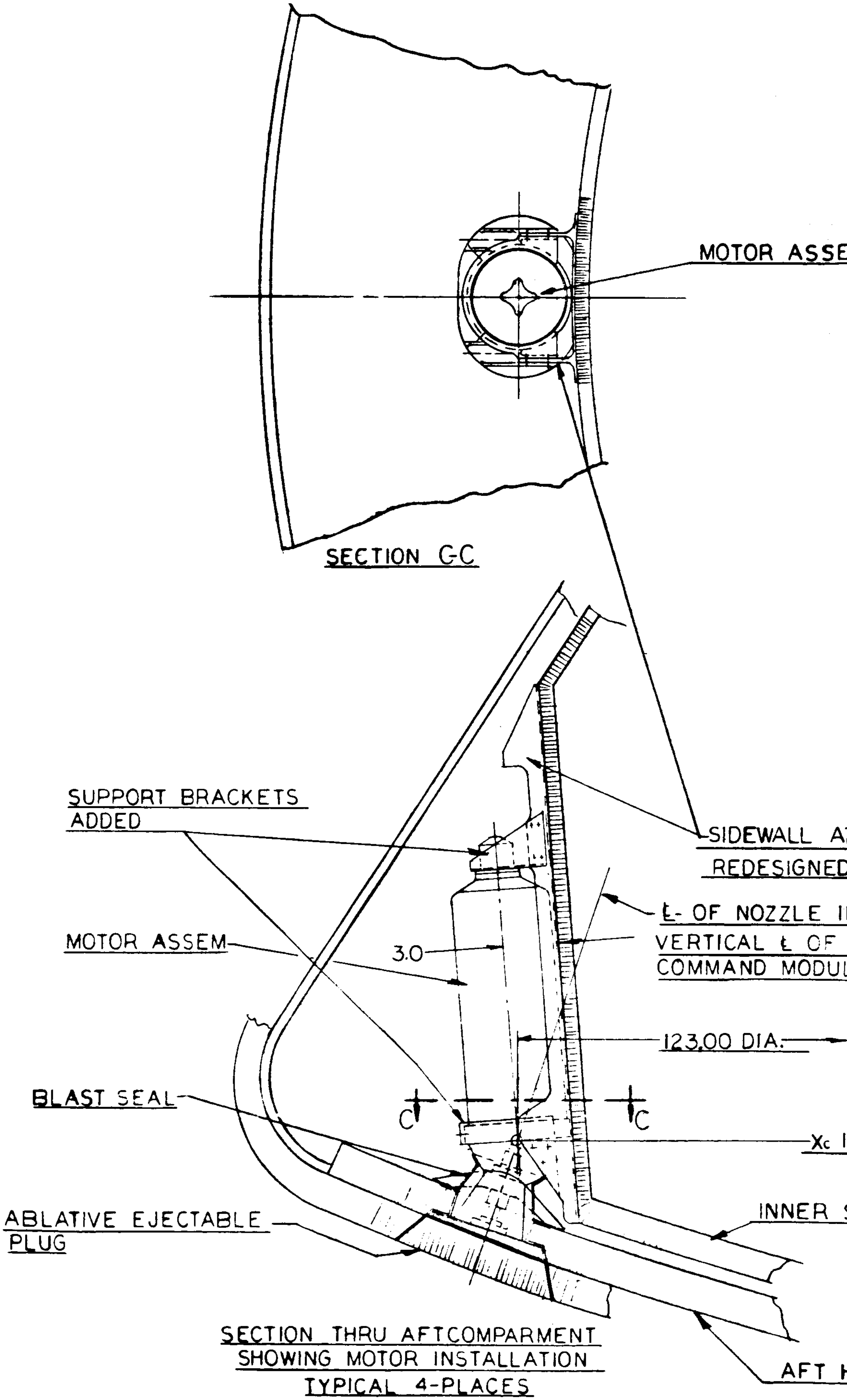
Installation of the landing leg extension and damping cylinder and the four retromotors in the command module aft compartment equipment bay will require the following revisions in the location of the subsystem components and the aft compartment frames:

1. The reaction control system motor switches located between Frames 1 and 2 will require repositioning in the same area due to installation of the landing leg extension and damping cylinder.

2. Frames 4 and 7 will require redesign to provide for installation of the retromotors at these locations. The Block II side wall attach fittings will be redesigned to provide support for the retromotors and attach provisions for the new frames.

3. Frame 5 will require redesign to accommodate installation of the landing leg extension and damping cylinder.

4. The arrangement of the fuel control panel between Frames 9 and 10 will require modification in the same area due to installation of the landing leg extension and damping cylinder.



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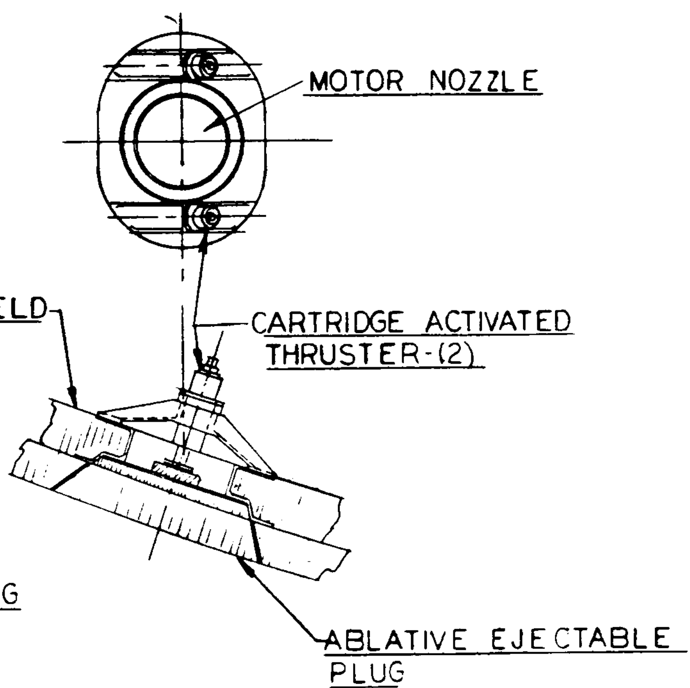
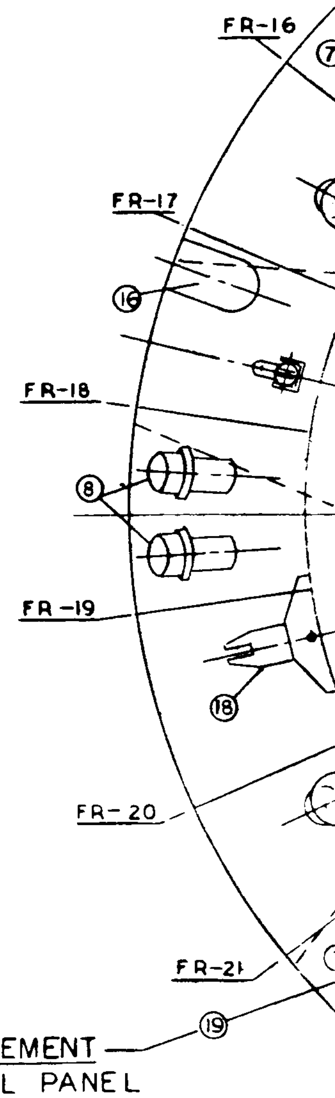


VIEW SHOWING
HEAT SHIELD EJECTION PLUG

7.3

STRUCTURE



POTABLE WATER TAN
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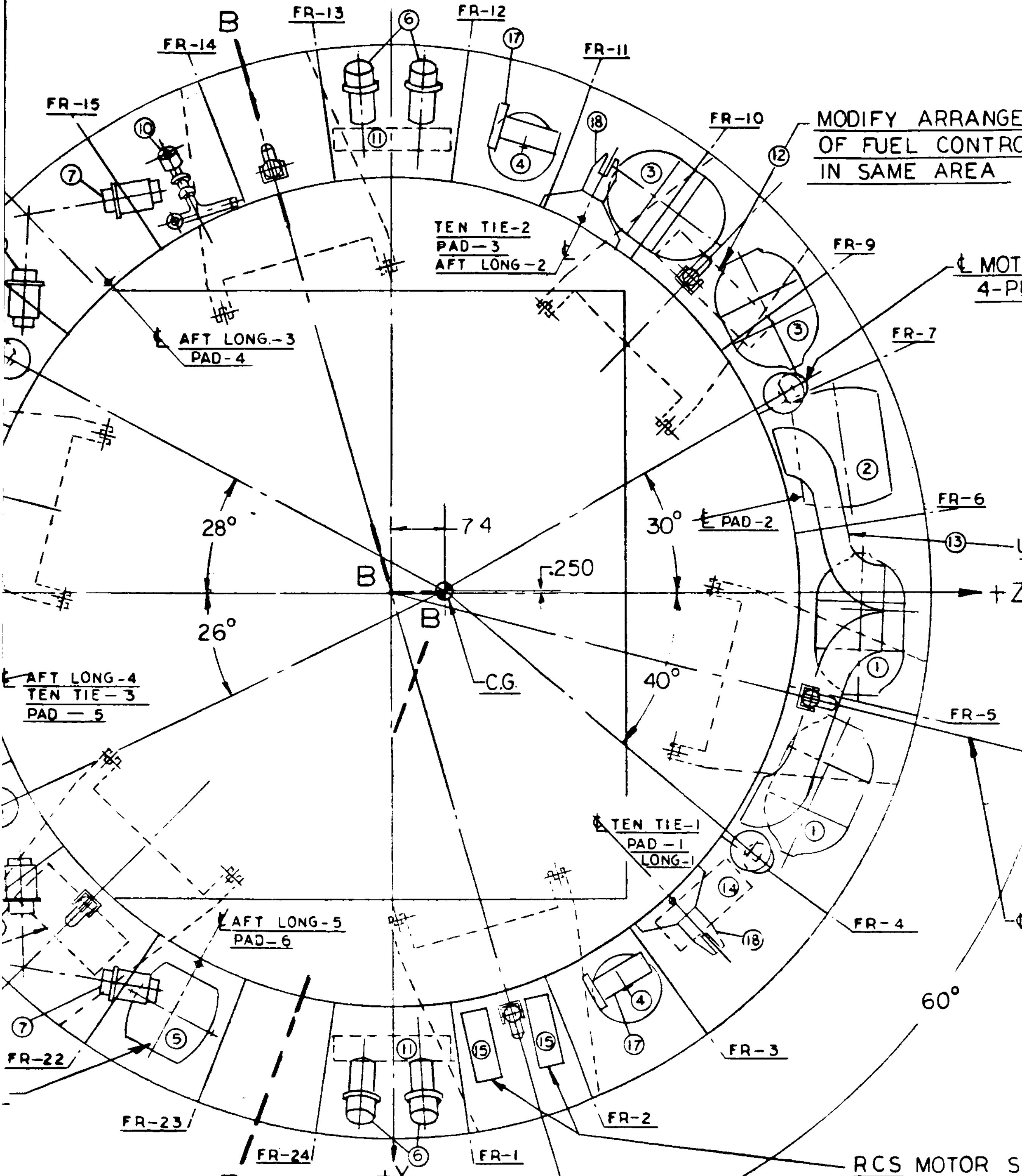
FR-13 & 14

IEAT SHIELD



SECTION-AA
SHOWING AFT EQUIP. BAY
LOOKING AFT

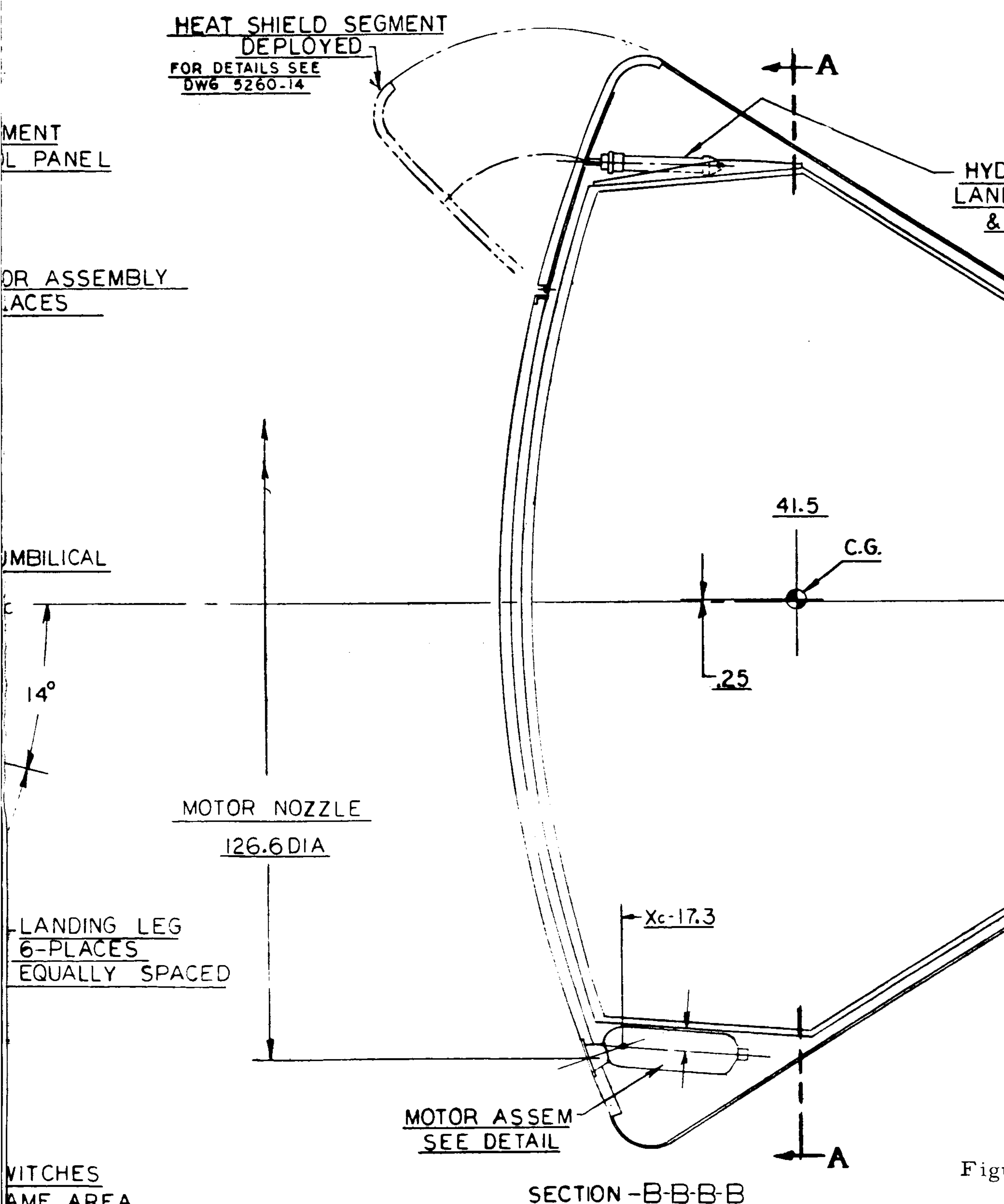

HEAT SHIELD SEGMENT DEPLOYED
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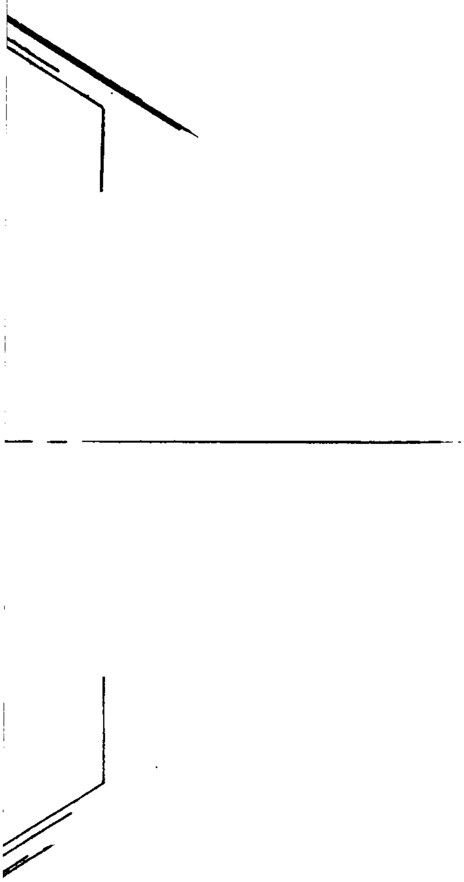
Fig

RAULIC CYLINDER
DING LEG EXTENSION
DAMPENING



1. OXIDIZER TANK 2
2. WASTE WATER TANK
3. FUEL TANK 2
4. HELIUM TANK 2
5. POTABLE WATER TANK
6. YAW RC ENGINE 4
7. ROLL RC ENGINE 4
8. PITCH RC ENGINE 2
9. RELIEF DUMP NOZZLE
10. STEAM VENT
11. HELIUM PRESSURE PANEL 2
12. FUEL CONTROL PANEL
13. ELECTRICAL UMBILICAL
14. OXIDANT CONTROL PANEL
15. RCS MOTOR SWITCH
16. AIR VENT
17. UPRIGHTING SYSTEM COMPRESSOR
18. TENSION TIE
19. RCS CONTROL PANEL

NOTE

ALL BLOCK-II EQUIP IN AFT COMP'T. REMAINS UNCHANGED EXCEPT AS NOTED

ıre 7. Retromotor Assembly Installation Segmented Heat Shield Concept MISDAS Study

5. The drinking water tank and plumbing located between Frames 13 and 14 will require relocating between Frames 22 and 23 to provide space for the landing leg extension and damping cylinder. New support structure for both the water tank and cylinder will be required.

6. The retromotors located between Frames 16 and 17 and between Frames 21 and 22 will require design of supports compatible with the present aft compartment structure.

7. The landing leg extension and dampening cylinders between Frames 17 and 18 and between Frames 21 and 22 will require design of support structure. The RCS control panel between Frames 21 and 22 will require modification to accommodate the landing leg and damping cylinder and its support structure which is added to this area.

Retromotor Installation

The retromotor support structure requires redesign of the Block II sidewall attach fitting at Frames 4 and 7 to provide for the retromotor support brackets (Figure 7) and for attachment of the new frame parts. The new sidewall attach fitting is used to support the retromotors between Frames 16 and 17 and between Frames 20 and 21, thus, making all four installations identical. The retromotor is installed through a door in the side of the conical heat shield structure. The forward end is entered through a hole in the upper support bracket, which would be already attached to the side wall fitting, and bolted through the support bracket to a flange on the retromotor.

The lower support bracket is attached to the retromotor in advance of installation. It is then placed between outstanding flanges of the sidewall attach fitting, which provides bolt holes to be used for securing the retromotor. The retromotor nozzle penetrates approximately three-fourths of the way through the aft heat shield to the point where the ejectable plug is secured. The opening continues through the outer ablative cover which incorporates an ejectable ablative plug. The plugs are ejected by two cartridge-activated thrusters located on each side of the retromotors. The thrusters are installed in a support which is secured to the aft heat shield structure as shown in Figure 7. A blast seal is installed around the lower end of the retromotor case and secured to the aft heat shield structure, preventing retro exhaust from entering the aft compartment.

STRUCTURAL ANALYSIS

To verify the technical feasibility of the six-segment heat shield concepts installation in AES, stress and deflection analyses were performed. These analyses included studies of the principal components of the impact attenuation system, the AES aft heat shield, and affected portions of the command module inner structure. The analyses were conducted to the depth required to determine critical design conditions, select materials, calculate required member sizes, provide a basis for weights analysis, and ensure that the command module inner structure is not damaged. The analyses are based on Figures 4, 5, and 6 and the design criteria presented in the Guidelines, Constraints, and Design Criteria section. Load paths are shown in Figure 8, and the results are summarized in Table 1. The stress analysis is presented as Appendix A of this report. The materials considered and their structural properties are discussed in Appendix C. The principal aspects of the structural study are discussed in the following paragraphs.

Critical Conditions

The critical design conditions are ground impact, water impact, 20-g entry, and boost abort. The land impact condition is critical for design of the shock strut, the shock strut attachment fitting, the inner structure, aft sidewall skins, the deployable legs, and the box section ring in the aft heat shield. The water impact condition designs the aft heat shield honeycomb panel skins within a radius of 58 inches. The 20-g entry condition is critical for design of the toroidal section of the heat shield. Boost abort loads design the heat shield-structure attachment.

Assumptions

The structural design criteria given in the Guidelines, Constraints, and Design Criteria section are consistent with the Apollo Requirements Manual, ARM-6 Specifications (Reference 5), with the following exceptions. The water impact condition was limited to a vertical velocity of 15 feet per second for a touchdown weight of 10,600 pounds. The ground impact condition was based on a shock strut load derived from the dynamic analysis. The following safety factors were used in the analysis:

1. Ground impact

Deployable legs	1.00
All other structure	1.33

2. Water impact

All structure	1.00

3. 20-g entry

All structure	1.50

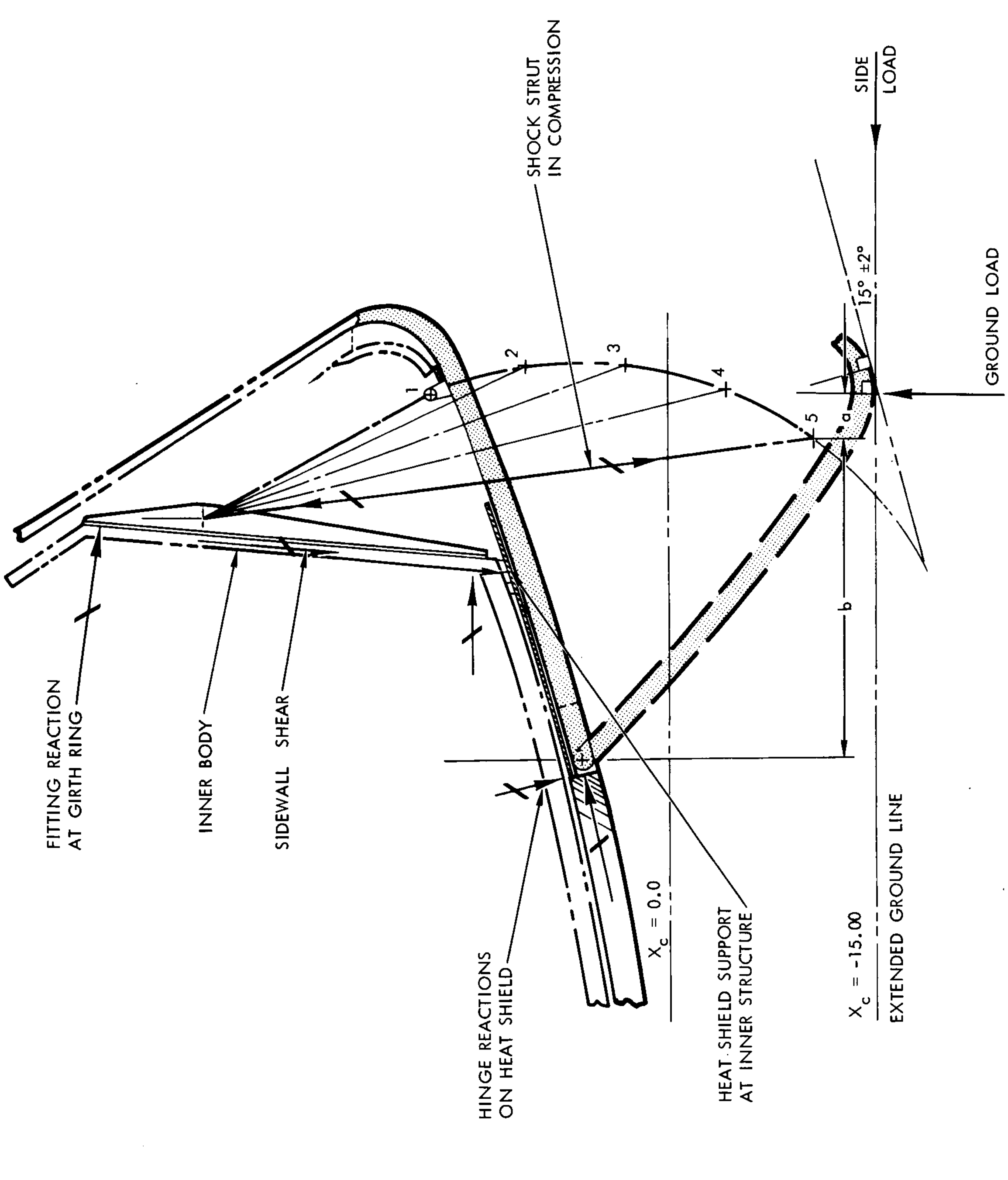


Figure 8. Load Path for Six-Legged System

Table 1. Critical Stresses and Margins of Safety for Six-Segment Heat Shield Concept

Item	Typical Material	Size	Critical Condition	Stress (psi)	Allowable Stress (psi)	Margin of Safety	Design Factor of Safety
Aft heat shield skin	Steel, PH14-8Mo	t = 0.045 to 0.008	Water impact	134,000	150,000	0.12	1.00
Aft heat shield core	Steel, PH14-8Mo	3/16 Cell 0.0015 Foil	Water impact	515	860	0.67	1.00
Toroidal corrugated skin	Steel, PH14-8Mo	t = 0.015	20-g entry	42,500	57,500 (buckling)	0.35	1.50
80-inch diameter ring	Steel, PH14-8Mo	t = 0.125	Ground impact	66,800	77,000 (after welding)	0.15	1.33
Deployable leg beams	Steel, PH14-8Mo	t = 0.156	Ground impact	83,600	105,000	0.25	1.00
Deployable leg skin	Steel, PH14-8Mo	t = 0.080	20-g entry	55,000	156,000	1.84	1.50
Deployable leg stiffeners	Steel, PH14-8Mo	t = 0.080	20-g entry	71,600	156,000	1.18	1.50
Shock absorber support fitting	Aluminum alloy 7075-T6		Ground impact	48,100	60,000	0.24	1.33
Inner structure aft sidewall skin	Aluminum alloy 2014-T6	t = 0.020	Ground impact	36,800	38,000	0.04	1.33
Inner structure aft sidewall skin to ring bond	Expoxy adhesive		Ground impact	975	1,320	0.35	1.33
Shock strut	Steel, PH14-8		Ground impact	81.000	91,000	0.12	1.33

The 1.33 factor for the structure was specified in Paragraph IV-A-11 of Exhibit A of Contract NAS9-4915. The factor of 1.00 is used for the components that impact the ground or water because these items are expected to yield on impact. The aft heat shield and deployable legs were analyzed for a temperature of 600 F and the inner structure for a temperature of 200 F. The value of 600 F is conservative in that it represents the maximum temperature which the heat shield-ablator interface will reach.

Aft Heat Shield Substructure

The aft heat shield substructure has been modified to accommodate the six deployable segments within the contour, with changes resulting in the available load paths. All loads are applied to the heat shield, either as distributed loads or loads concentrated at selected points. These loads are then reacted by the aft bulkhead ring of the inner structure. The primary load path assumed is through that portion of the aft heat shield substructure that has retained a full 2-inch depth. A secondary load path is available through that area of the structure that has been reduced to 0.50-inch thick honeycomb panels. Conservatively, and for simplicity of analysis, these 0.50-inch panels have been assumed to carry no primary loads; however, their presence is essential to the heat shield structure to minimize differential deflection between the segments during atmospheric entry and to provide a water-tight compartment for water impact. A box section ring 86 inches in diameter has been welded into the structure to pick up the deployable leg hinges. Within this ring, loads are reacted by tangential forces; outboard of the ring, the 2-inch-deep segments carry the loads in bending to the inner structure aft bulkhead ring. The loss of hoop continuity in the toroidal portion of the aft heat shield has been compensated for by an increase in the depth of the corrugated sheet.

Deployable Legs

The land impact loads on the deployed legs are applied to the outer skin and reacted by a shock strut and two hinges per leg. To achieve the required bending and torsional stiffness in the limited depth available, the legs have been designed as box sections of riveted construction. Stiffeners have been added to the outer skin of the legs to provide panel stiffness equivalent to the fixed portion of the heat shield.

Command Module Inner Structure

The aft heat shield is bolted to the inner structure at the aft bulkhead ring with 36 bolts. To react the tensile loads present in the boost abort condition, 7/16-inch bolts are required. The forward end of the shock strut is attached to a fitting which introduces the loads to the inner structure aft sidewall. This fitting is bolted to the girth ring, and the aft bulkhead ring,

and is bonded to the aft sidewall skin. The radial component of the shock strut load is carried in bending by the fitting and is reacted by the rings. The vertical component is carried by the bond between the fitting and the sidewall. The resulting shear in the aft sidewall skins requires a face sheet thickness of 0.020 inch.

Results

The design concept shown in Figure 4 can satisfy the structural design criteria. The member sizes derived from this study were used to calculate the system weights shown under Mass Properties discussion for the six-segment concept. Preliminary deflection analyses indicate that the command module inner structure will not be damaged for the design landing conditions. Table 1 shows the critical condition, stress, and margin of safety for each major component. The stress calculations are presented in Appendix A of this report.

STABILITY ANALYSIS

Stability analyses have been performed either to establish the fact that the spacecraft does not turn over during landing, or to determine the range of vehicle velocities, vehicle attitudes, shock strut characteristics, and ground conditions under which stable landings can be achieved. To perform these analyses, a computer program was developed to calculate and record the motion of the spacecraft about three axes as a function of time after ground contact. The stability program is described in detail in Reference 7. Results of the stability analysis are summarized below.

The program is based on assumptions of massless legs, rigid spacecraft hull, rigid ground plane, and shock strut load-stroke characteristics that can be represented by a series of straight lines.

Program inputs include:

1. Spacecraft geometry

    a. Center of gravity coordinates

    b. Weight

    c. Mass properties

    d. Number of struts - end coordinates

    e. Load - stroke characteristics

2. Landing velocities V_V and V_H

3. Hang angles

4. Roll

5. Parachute swing angle and direction of swing

6. Ground slope and direction of slope

Program outputs include:

1. Roll, pitch, and yaw versus time

2. Displacement, velocity, and acceleration versus time

3. Strut stroke versus time (each strut)

4. Maximum total center of gravity acceleration

5. Maximum tipping angle

Angle Conventions

To define roll, pitch, and yaw, the vehicle is first rolled about its vertical axis, then pitched about its y axis, then yawed about the z axis on the capsule. The roll angle is always measured as the counterclockwise angle from the horizontal velocity to the vertical plane containing the capsule z axis. The net pitch angle is measured as the upward angle from the horizontal plane to the capsule z axis. Axis convention is identified in Figure 9.

The ground slope is defined by a maximum slope and a direction of upslope. The direction of upslope is measured in a counterclockwise angle (right-hand rule) from the horizontal velocity. Positive slope is upslope.

The vehicle attitude may be defined by a parachute swing angle and its direction of swing. The direction of swing is defined as the angle between the vertical plane containing the capsule z axis and the vertical plane containing the parachute riser lines. Positive swing and zero direction of swing are the same as positive pitch angle

Horizontal and vertical velocity always form the basic reference plane.

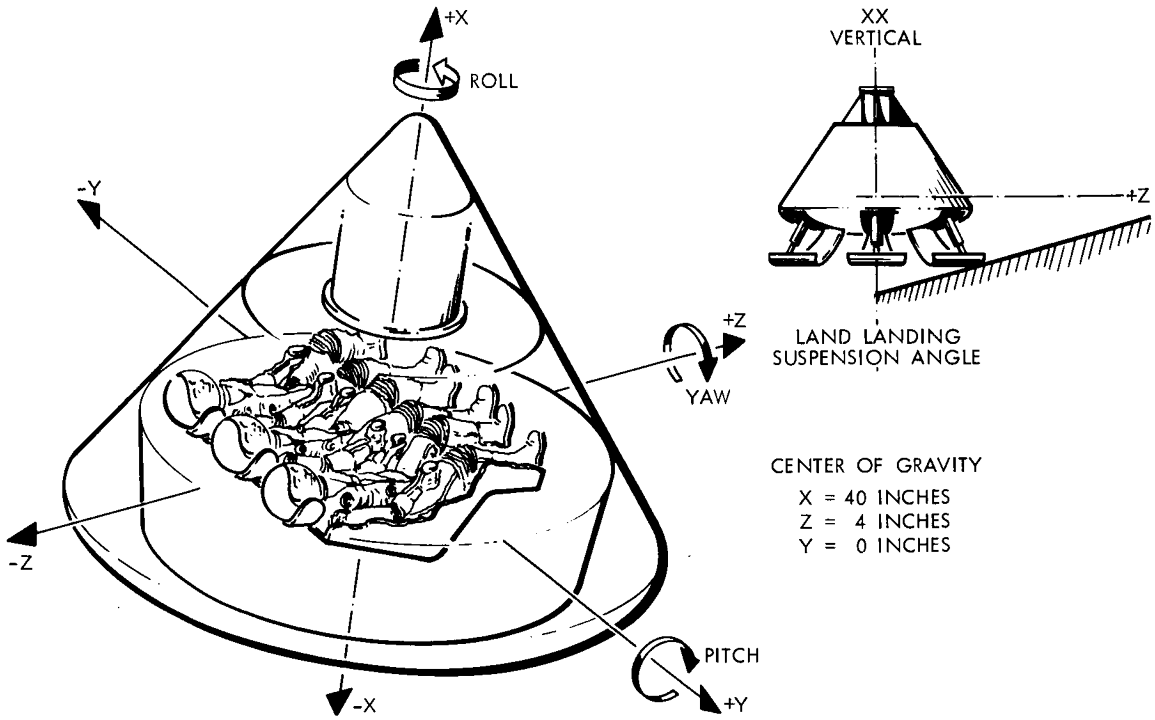


Figure 9. MISDAS/AES Land Landing Attitude, Six-Legged System

Legged Vehicle Data

The specific vehicle used in the stability analysis had the following properties, derived from AES weight data (Reference 8); including estimates of the effects of incorporating the MISDAS installation.

Weight = 10,600 lb
I_{xx} = 5,204 slug ft^2
I_{yy} = 3,941 slug ft^2
I_{zz} = 3,662 slug ft^2
No. of legs = 6

The geometry of the vehicle in capsule initial system coordinates (x = y = z = 0 at center of heat shield), as obtained from Figure 4 is:

Item	x	y	z
Center of gravity (in.)	36.9	1.79	6.25
Movable strut tips (in.)			
Leg 1	-15.0	-34.67	60.05
Leg 2	-15.0	-69.34	0.0

Item	x	y	z
Leg 3	-15.0	-34.67	-60.05
Leg 4	-15.0	-34.67	-60.05
Leg 5	-15.0	69.34	0.0
Leg 6	-15.0	34.67	60.05
Fixed strut tips (in.)			
Leg 1	40.0	-34.67	60.05
Leg 2	40.0	-69.34	0.0
Leg 3	40.0	-34.67	-60.05
Leg 4	40.0	34.67	-60.05
Leg 5	40.0	69.34	0.0
Leg 6	40.0	34.67	60.05

Strut Load-Stroke Characteristics

Strut load-stroke properties were the same for each of the six legs. Each leg strokes (in capsule initial coordinates) from the initial location of the movable strut tip toward the fixed strut tip. The path of motion is a straight line. Load-stroke properties for each strut are as shown in Figure 10. This load-stroke curve is for a mathematical representation of a strut in direct contact with the ground. The stress analysis was based on strut loads of 31300 pounds, based on the actual location of the strut.

The strut maximum displacement, limited by the capsule geometry, was used as the basis to derive the strut load-stroke characteristics. The properties shown in Figure 10 are those of a strut that will save the inner structure from damage without exceeding the crew onset rate and maximum acceleration capabilities. The load-stroke characteristics of the strut can be varied slightly without either exceeding the crew tolerances or making the spacecraft unstable.

All shock absorber manufacturers consulted agreed on the feasibility of the concept used in the study. Appendix B presents an initial evaluation of the shock strut from the Cleveland Pneumatic Tool Company, indicating only normal engineering development is required to produce a strut with the desired characteristics.

The actual vehicle strut acts between a hinged shoe and the vehicle. Due to the geometry of the hinge arrangement, as shown in Figure 4, the actual vehicle strut will be stiffer and will have a shorter ramp than for the mathematical model strut used in the stability analysis.

Crew Compartment Acceleration

The strut loads used on the legged vehicle result in total accelerations on the crew compartment, which are less than maximum allowable Apollo values, as given in Reference 5. The crew compartment will experience a 14.2-g acceleration normal to the ground plane and an onset rate of 28.4 g/sec for a landing with 80-fps horizontal velocity toward a 5-degree upslope, 15-fps vertical velocity, and angular attitude such that 6 legs contact simultaneously. For a 0.35 coefficient of friction, the total acceleration will be 15.0 g. This landing has resulted in the most severe accelerations. It represents the condition of maximum normal velocity (22 fps) with all struts stroking simultaneously.

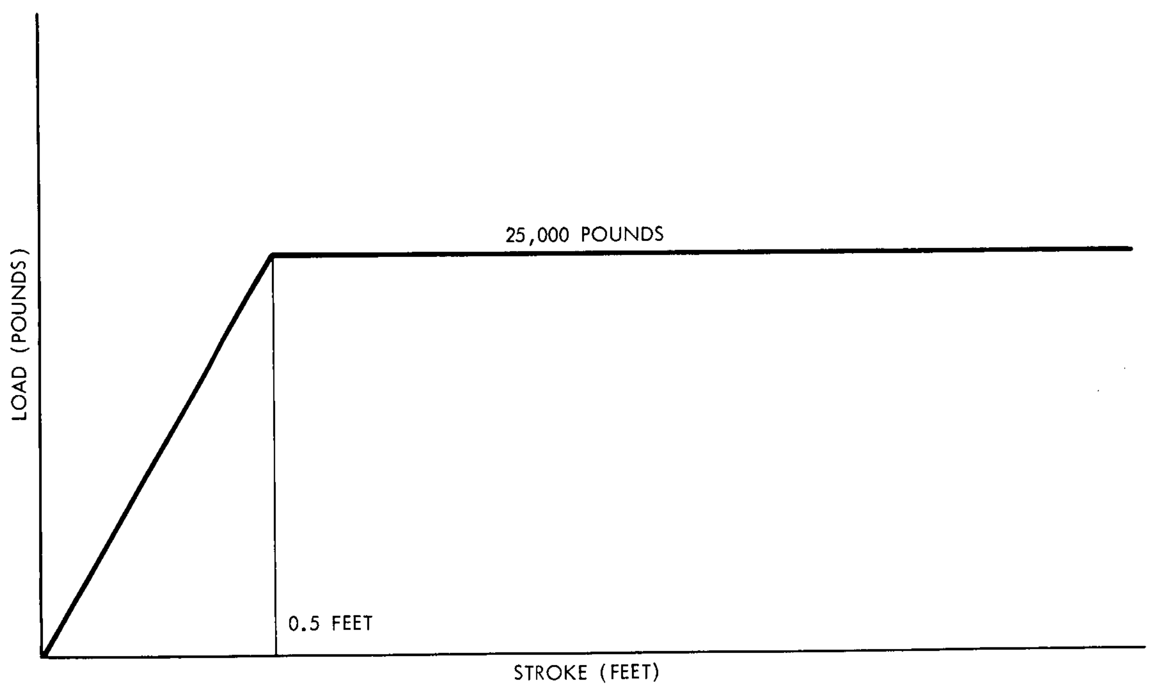


Figure 10. Load-Stroke Curve for Legged Vehicle With Six Vertical Struts

Stability of Legged Vehicle

The six-leg vehicle was found to be stable within the landing criteria presented under Guidelines, Constraints, and Design Criteria. For a vertical velocity less than or equal to 15 fps and coefficient of friction equal

to 0.35, the vehicle showed stability for the specified combinations of the random variables of slope, slope direction, roll, chute swing angle, and chute swing direction. The worst landing condition was for horizontal velocity toward a 5-degree downslope, roll = 0, direction of swing = 0, swing angle = +12 degrees. Even under these conditions the capsule only slightly exceeded the initial 17-degree angle which the capsule x axis made with a ground normal (Tables 2 and 3).

A quantity called maximum tipping angle is tabulated in the summary sheets (Tables 2 and 3). This angle is the maximum value in degrees that the capsule x-axis forms with a ground normal during a landing. Only one landing at 15 fps vertical velocity had a maximum tipping angle greater than the initial impact angle.

A few runs made at 20 fps vertical velocity resulted in somewhat greater maximum tipping angles. The worst landings of these runs are at approximately zero roll angle, with horizontal velocity toward downslope, and capsule attitude such that a 17-degree angle is formed by the ground plane and the capsule y-z plane.

The stability summary sheets (Tables 2 and 3) also tabulate the maximum stroking executed by a single strut during families of landings. The most severe landings with regard to strut stroking were made upslope at 80-fps horizontal velocity (Table 3). Upslope landings caused maximum strut stroking, but had the net effect of stabilizing the spacecraft.

No unstable landings were encountered within the landing criteria; therefore, it is difficult to present a stability envelope graphically. However, Figure 11 shows the maximum tipping angles mapped as a function of vertical velocity and roll angle. The low values of these angles indicate good stability.

MASS PROPERTIES

To conform with the AES engineering weight data, the Apollo Block II weight data given in Reference 9 was utilized as a base point to determine the weight penalty for adding a mechanical impact landing system. The weight penalty of the mechanical landing system is the weight of the landing gear system and the effect of all modification required on the aft heat shield structure and on the inner structure.

The spacecraft includes the retrorocket system with associated systems as developed from the AES Land Landing Study (LLS) to obtain a vertical descent velocity of 15 feet per second. Minor modifications, reflected in the weight breakdown, made the LLS design data compatible with the MISDAS installation.

To establish a realistic volumetric comparison, only the volume penalty in the aft equipment bay was assessed. In this study the volume penalty is considered the total volume displaced by the components including the space provided for the movement of the struts and rocket motors.

Table 4 presents the detail weight breakdown of the six-segmented heat shield landing concept, including the retrorocket system and its associated systems necessary to obtain a desired impact velocity. Weight analysis of the segmented heat shield landing gear system shown in Figures 4, 5, and 7 is based on detail structural analysis presented in Appendix A of this report, with allowance for items not shown in the figures and estimates for subsystems based on the AES spacecraft data.

The landing gear system consisting of a leg assembly, leg support frame, shock strut assembly, hydraulic and pneumatic system, and a leg release mechanism was calculated to weigh 734 pounds. This amounts to 6.92 percent of the design landing weight. The weight penalty of the mechanical landing system is the net weight penalty of the landing gear system weight with the weight change of the aft heat shield structure and the inner structure. This net weight penalty amounts to 556 pounds (5.25 percent). The MISDAS heat shield weight reduction over the weight of the AES heat shield in obtained by consideration of reduced water impact velocities, and is based on the calculated weight of the AES and MISDAS heat shields.

MANUFACTURING CONSIDERATIONS

This section presents a manufacturing plan for the six-legged landing system shown in Figures 4, 5, and 6. Although the overall landing system configuration shown in the drawings has been retained, a limited number of structural details have been modified to enhance the producibility of the installation. These changes have been incorporated in the structural analysis. The pictorial manufacturing plan shown in Figure 12 illustrates a sequence of assembly to produce the finished landing system hardware utilizing current state-of-the-art techniques and many of the existing Apollo tools.

Aft Heat Shield Fabrication

Although the aft heat shield from which the six landing legs deploy is similar in appearance to the present Apollo aft heat shield, all details of this assembly should be considered new. The new assembly will still bolt to the bottom of the inner crew compartment and provide a seal with the inner crew compartment heat shield at the mold line surface.

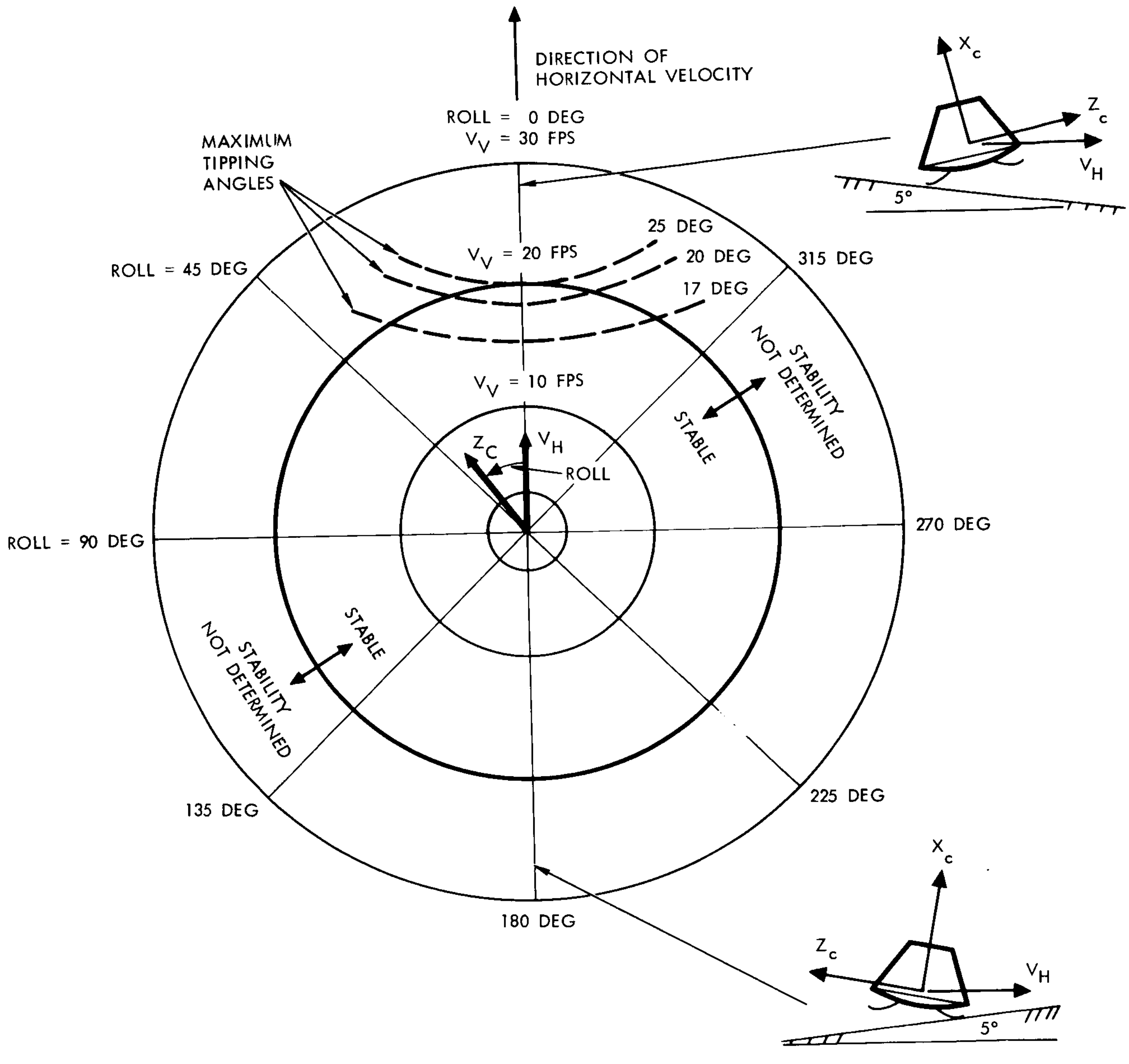
Job No.	Horizontal Velocity	Vertical Velocity	Roll	Pitch	Yaw	Slope	Direct Slope
60	30	15	0	0	0	-5	0
			22.5				22.5
			45				45
			67.5				67.5
			90				90
			30				0
			52.5				22.5
			75				45
			97.5				67.5
		15	120				90
		20	0				0
			22.5				22.5
			45				45
			67.5				67.5
			90				90
			30				0
		20	52.5	0			22.5
		15	0				0
			75				45
			97.5				67.5
Vehicle per Figure 4, Drawing using stability axes	30	15	120	0	0	-5	90
61	30	15	0	0	0	-5	0
			22.5				
			45				
			67.5				
			90				
			30				
			52.5				
			75				
			97.5				
			120.0				0
			0				45
			22.5				
			45				45
			0				0
			67.5				
			90				
			30				
			52.5				
			75				
			97.5				
V...icle per Figure 4, Drawing using stability axes	30	15	120	0	0	-5	0

Table 2. Six Leg Vehicle Stability Summary, V_H = 30 fps

Friction	Swing	Direct Swing	Stability	Legs Touchdown Initial	Notes	Maximum Tipping Angle
0.35	12	0	All stable, maximum strut stroke = 1.15 ft	2	Loadstroke data: 0.5 ft ramp, 30,033 lb maximum load	17
						17
						17
						17
				2		17
	-30			1		17.1
						17
						17
						17
		-30		1		17
		0	All stable, maximum stroke = 1.6 ft	2		23.1
						18.0
						17
						17
				2		17
		-30		1		25.9
		-30		1		19.5
		0		2		17
						17
						17
0.35	12	0		2		17
0.35	12	0		2		17.0
						16.7
						15.9
						14.6
						13.0
		-30				17.0
						16.7
						15.9
						14.6
		-30				13.0
		0				15.9
						16.7
						17.0
						17.0
						16.7
		0	All stable, maximum strut stroke = 1.18 ft			15.9
		-30				15.9
						16.7
						17.0
						16.7
0.35	12	-30		2		15.9

Table 3. Six Leg Vehicle Stability Summary, V_H = 80 fps

Job No.	Horizontal Velocity	Vertical Velocity	Roll	Pitch	Yaw	Slope	Direct Slope	Friction	Swing	Direct Swing	Stability	Legs Touchdown Initial	Notes	Maximum Tipping Angle
62	80	15	0	0	0	+5	0	0.35	-12	0		2		1.31
			45				45					2		1.18
			30				0			-30		1		1.43
Vehicle per Figure 4, using stability axes		15	75				45			-30	All stable	1	Maximum angle 17° initial impact angle	1.26
		20	0				0			0		2		1.69
			45				45			0		2		1.59
			30				0			-30		1		1.77
	80	20	75	0	0	+5	45	0.35	-12	-30		1		1.57



MAXIMUM TIPPING ANGLES MAPPED AS A FUNCTION OF VERTICAL VELOCITY (FPS) AND ROLL ANGLE (DEGREE)

THE CAPSULE Y-Z PLANE IS AT A CONSTANT 17-DEGREE ANGLE WITH GROUND PLANE. (12 DEGREES PARACHUTE SWING ANGLE PLUS -5 DEGREES GROUND SLOPE COMBINED FOR MAXIMUM ANGLE WITH GROUND.) DIRECTION OF SLOPE HAS BEEN COORDINATED WITH ROLL TO PROVIDE ONE AND TWO LEG INITIAL CONTACT. V_H = 30 FPS. FRICTION COEFFICIENT = 0.35.

Figure 11. Stability Limits for Six-Leg Vehicle

Table 4. Weight of Segmented Heat Shield Concept

Item	Weight (lb)		
	Apollo Block II (Sept. 65)	AES Addendum	Weight Change
Aft Heat Shield Structure	(763.3)	(579.3)	(-184.0)
Honeycomb panel*	(559.6)	(376.0)	(-183.6)
Core	202.9	160.0	- 42.9
Face sheets	305.6	165.0	-140.6
Braze	51.1	51.0	- 0.1
Frames and rings**			
Ring - outer rim	55.1		- 55.1
Body to heat shield attachment	55.9	37.0	- 18.9
Fitting and attachment	33.0	33.0	0.0
Closeouts***	7.1	21.0	13.9
Toroidal assembly****	(52.6)	(112.3)	(59.7)
Corrugation	16.6	28.0	11.4
Skin	17.7	18.0	0.3
Splice and attach	18.3	22.3	4.0
Rim		44.0	44.0
Inner Structure - Aft Section			
Honeycomb panels	122.0	128.0	6.0
Landing Gear System		(734.0)	(734.0)
Leg assembly		(427.0)	427.0
Skin		160.0	
Stiffeners		150.0	
Edge members		76.0	
Hinge fittings		20.0	
Strut attach fittings		18.0	
Hardware		3.0	

*Honeycomb panel — reduced core density and face sheet thickness to conform to decrease in landing load

**Frames and rings — outer rim ring segmented and reallocated under toroidal assembly and leg assembly

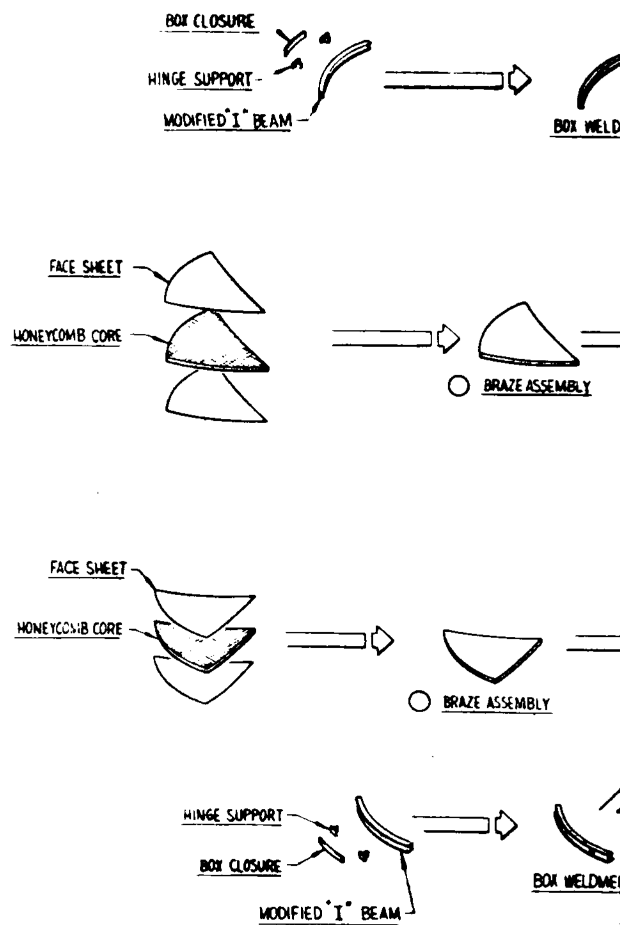
***Closeouts — edge members provided around deployable legs

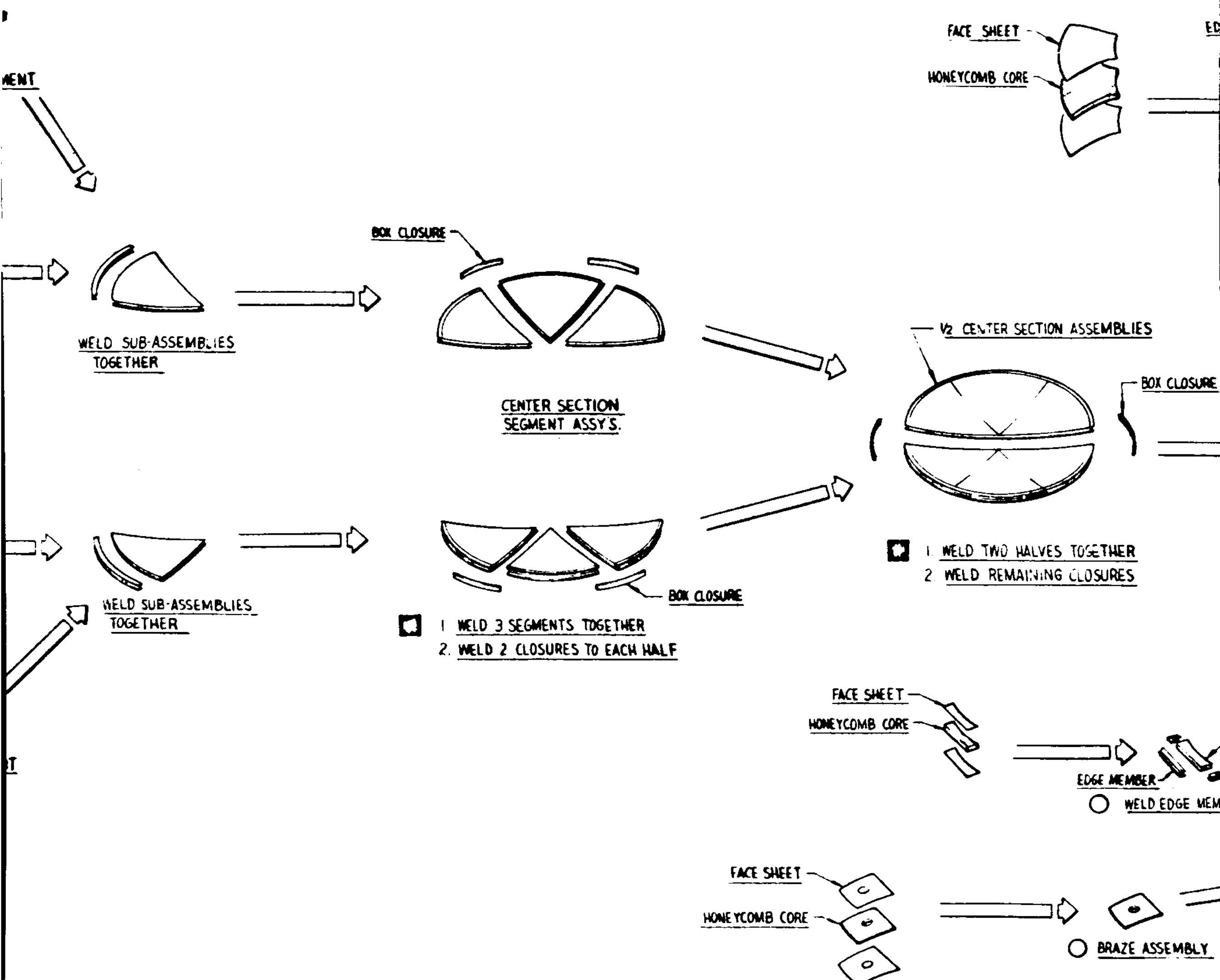
****Toroidal assembly — modified toroidal assembly to accommodate leg assembly and included part of the outer rim ring

Table 4. Weight of Segmented Heat Shield Concept (Cont)

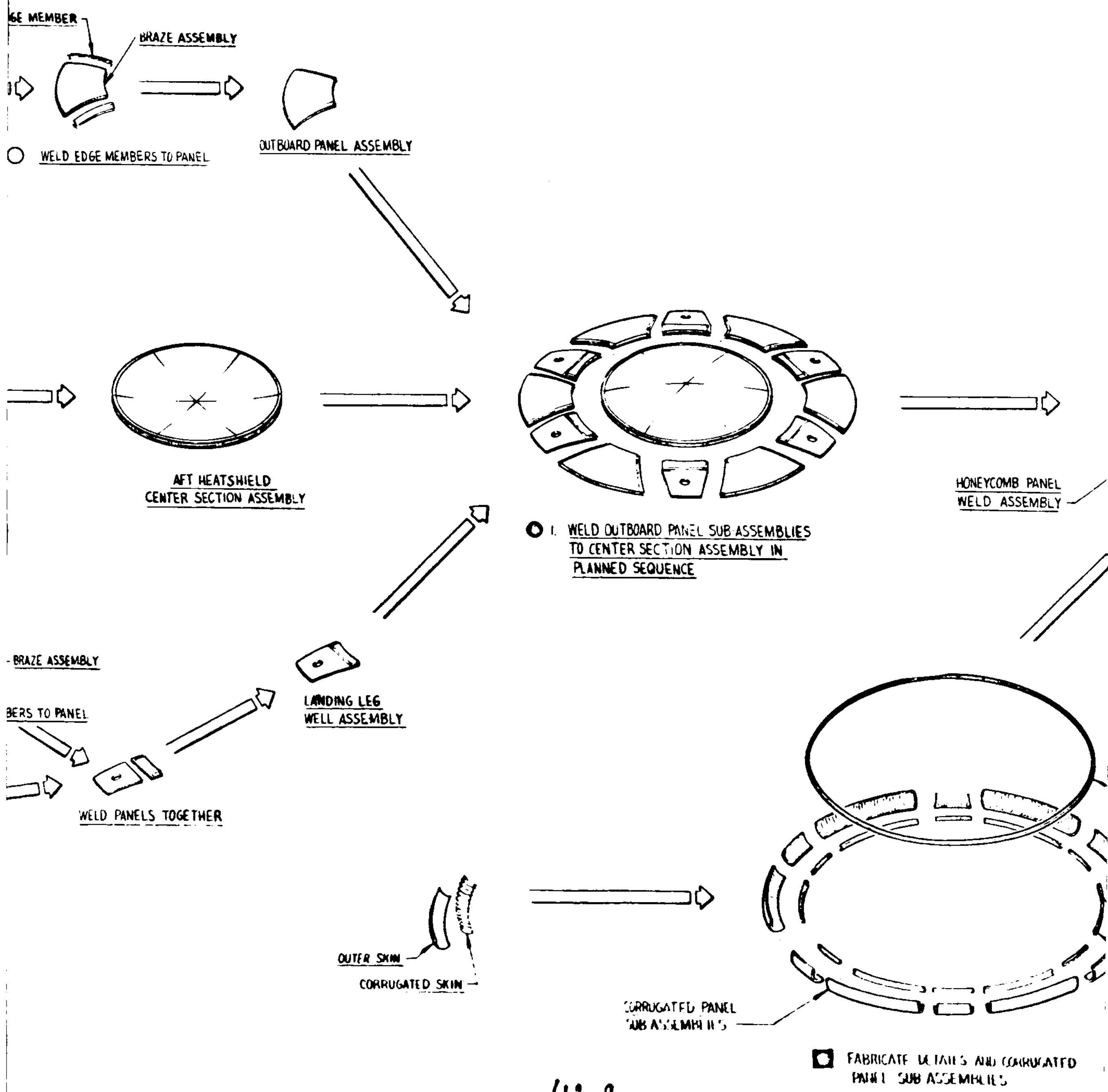
Item	Weight (lb)		
	Apollo Block II (Sept. 65)	AES Addendum	Weight Change
Frame - leg support		(126.0)	126.0
Shock strut assembly		(122.0)	122.0
Struts (6)		90.0	
Attach fittings - sidewall		25.0	
Conical bellows		3.0	
Hardware		3.0	
Hydraulic and pneumatic system		52.0	52.0
Hydraulic accumulator		12.5	
Motor valve		2.0	
Valves		0.5	
Dampening orifices		1.0	
Plumbing		7.0	
Electrical provision		2.5	
Support and attaching parts		1.5	
Hydraulic fluid		24.0	
Gas (helium)		1.0	
Leg release mechanism		7.0	7.0
Subtotal	885.3	1441.3	556.0
Total Mechanical Landing System Penalty (Usable volume displaced - ft^3)			556.0 (2.8)

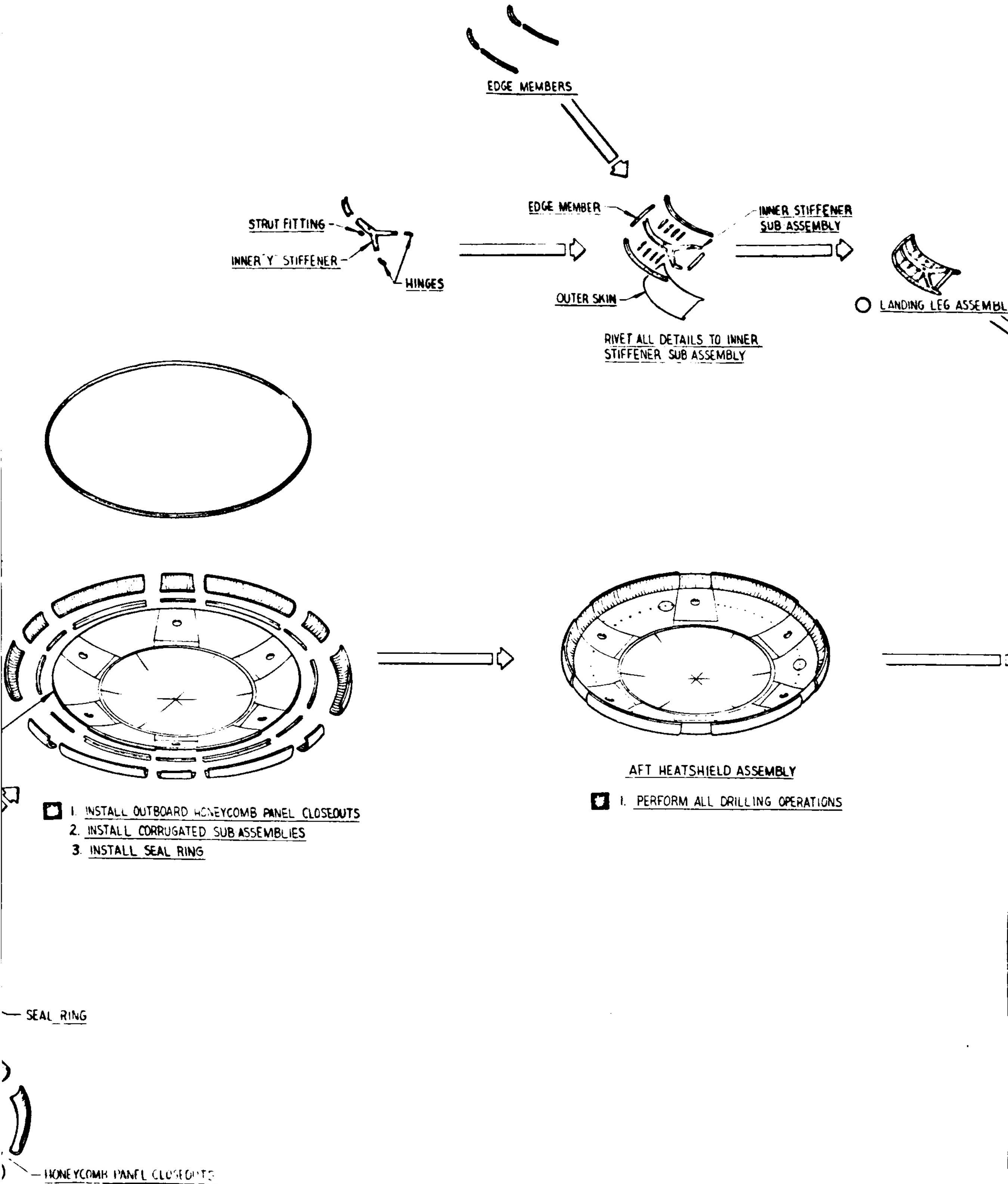
As shown in Figure 12, the center section of the aft heat shield has been divided into six segments, rather than one full honeycomb panel braze assembly with unpredictable faying surface braze joints. From past experience, reliability of faying surface braze joints in brazed sandwich panels has

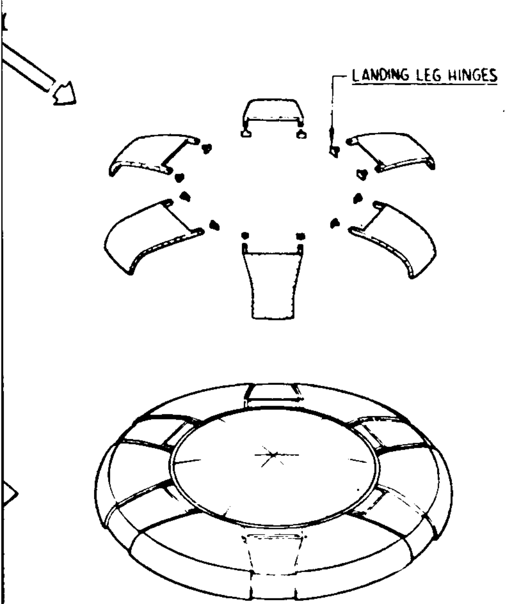

BOX CLOSURE
HINGE SUPPORT
MODIFIED "I" BEAM
BOX WELD
FACE SHEET
HONEYCOMB CORE
BRAZE ASSEMBLY
FACE SHEET
HONEYCOMB CORE
BRAZE ASSEMBLY
HINGE SUPPORT
BOX CLOSURE
MODIFIED "I" BEAM
BOX WELDME



FACE SHEET
HONEYCOMB CORE
BOX CLOSURE
WELD SUB-ASSEMBLIES TOGETHER
CENTER SECTION SEGMENT ASSY'S.
1/2 CENTER SECTION ASSEMBLIES
BOX CLOSURE
1. WELD TWO HALVES TOGETHER
2. WELD REMAINING CLOSURES
WELD SUB-ASSEMBLIES TOGETHER
BOX CLOSURE
1. WELD 3 SEGMENTS TOGETHER
2. WELD 2 CLOSURES TO EACH HALF
FACE SHEET
HONEYCOMB CORE
EDGE MEMBER
FACE SHEET
HONEYCOMB CORE
BRAZE ASSEMBLY

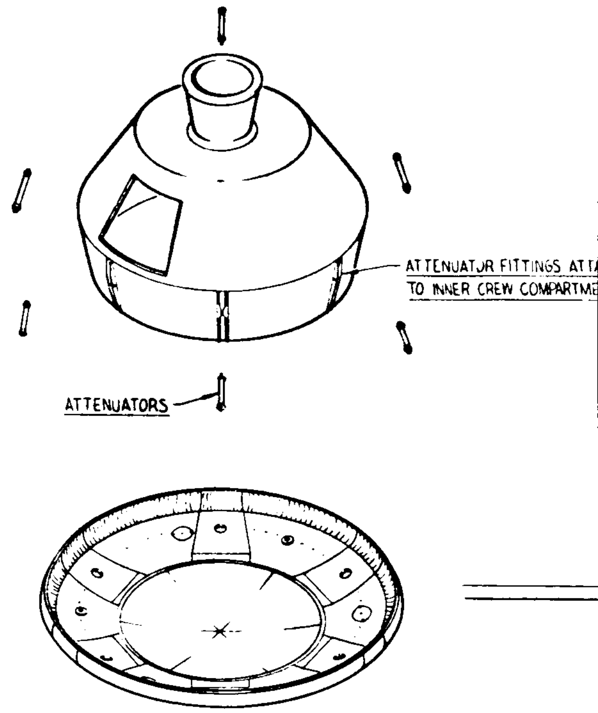

GE MEMBER
BRAZE ASSEMBLY
WELD EDGE MEMBERS TO PANEL
OUTBOARD PANEL ASSEMBLY
AFT HEATSHIELD
CENTER SECTION ASSEMBLY
1. WELD OUTBOARD PANEL SUB ASSEMBLIES
TO CENTER SECTION ASSEMBLY IN
PLANNED SEQUENCE
HONEYCOMB PANEL
WELD ASSEMBLY
BRAZE ASSEMBLY
BERS TO PANEL
LANDING LEG
WELD ASSEMBLY
WELD PANELS TOGETHER
OUTER SKIN
CORRUGATED SKIN
FABRICATE DETAILS AND CORRUGATED
PANEL SUB ASSEMBLIES


EDGE MEMBERS
STRUT FITTING
INNER 'Y' STIFFENER
HINGES
EDGE MEMBER
INNER STIFFENER SUB ASSEMBLY
OUTER SKIN
RIVET ALL DETAILS TO INNER STIFFENER SUB ASSEMBLY
LANDING LEG ASSEMBL
1. INSTALL OUTBOARD HONEYCOMB PANEL CLOSEOUTS
2. INSTALL CORRUGATED SUB ASSEMBLIES
3. INSTALL SEAL RING
AFT HEATSHIELD ASSEMBLY
1. PERFORM ALL DRILLING OPERATIONS
SEAL RING
HONEYCOMB PANEL



LANDING LEG INSTALLATION

1. INSTALL HINGES ON CENTER BOX STRUCTURE
2. CUSTOM FIT EACH LANDING LEG ASSEMBLY



AFT HEATSHIELD FIT CHECK

1. BOLT AFT HEATSHIELD TO INNER CREW COMPARTMENT
2. ATTACH ATTENUATORS
3. DEPLOY LANDING LEG ASSEMBLIES
4. CHECK DEPLOYMENT CLEARANCES ON ALL COMPONENTS

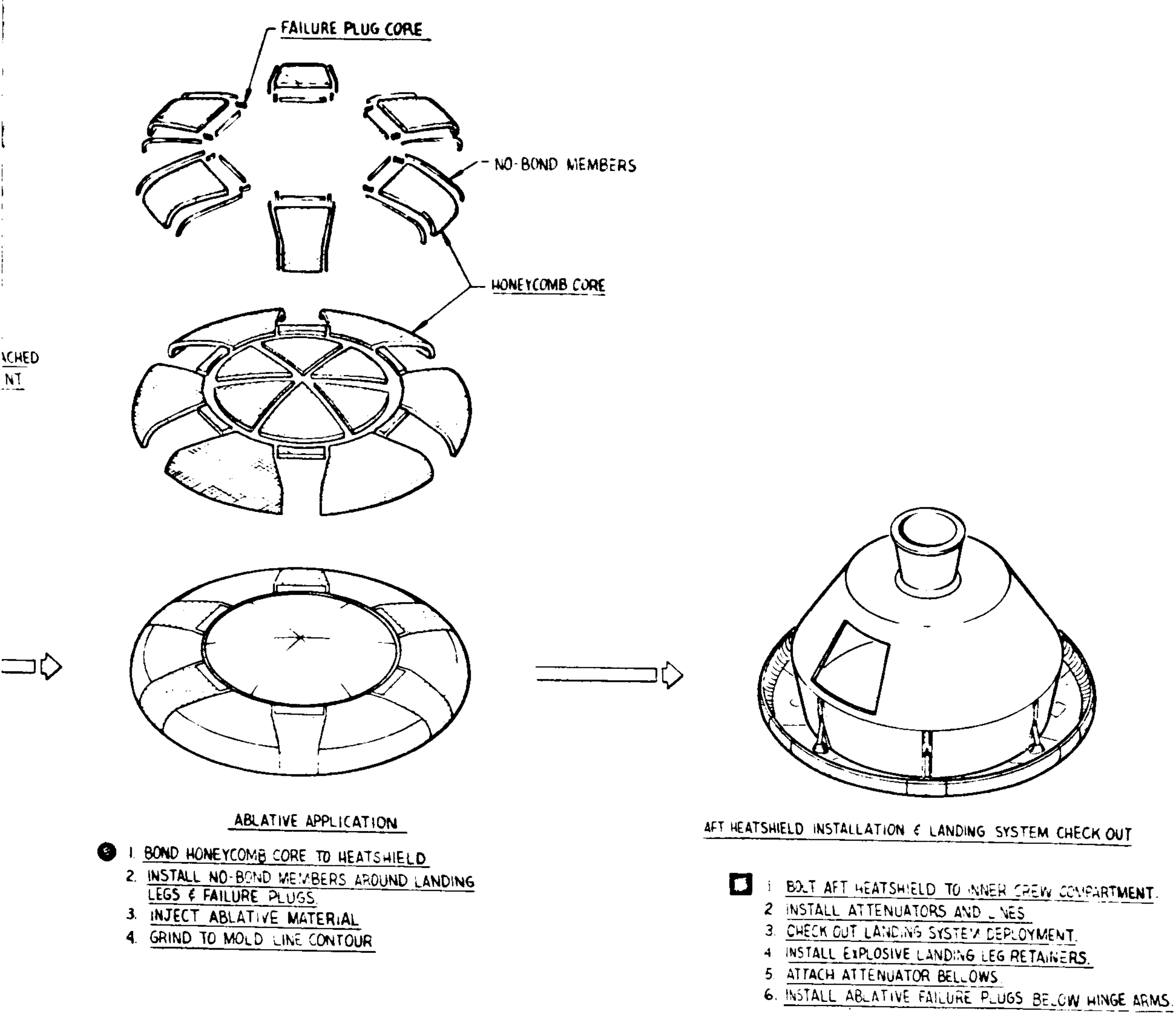


Figure 12. Manufacturing Breakdown, MISDAS Study Six-Leg Landing System

been questionable. On the other hand, the reduction of faying surface braze joints results in smaller panel sizes, imposing additional fusion weld requirements. Although the more reliable panel configuration is recommended, fabrication development of the one-piece center section braze assembly, including the landing leg stiffening ring member, is feasible.

As proposed in Figure 12, each of the six pie-shaped center section segments consists of one honeycomb panel braze assembly and one stiffening ring weldment. All assemblies are compound contoured. Two formed chem-milled face sheets and one 2-inch thick honeycomb core comprise the braze assembly. The panel will be fabricated with extra material around the periphery for subsequent trimming operations. Each weld assembly consists of one modified "I" beam main ring member, two hinge support members, and one rolled closure which forms the outer side of the box section between the two hinge supports. All details will be heat-treated before welding into an assembly. The ring section will be machined in the heat-treated condition. Additional material will be provided on the weldments for subsequent trimming operations.

To complete the pie-shaped center section segment assembly, the honeycomb panels must first be prepared for welding to the ring member weldments. This is accomplished by the removal of a small portion of the core and the brazing alloy deposit from both face sheets in the area to be welded. The honeycomb panel and weldment must then be match trimmed before subsequent tacking and simultaneous butt fusion welding of the upper and lower surfaces. Progressively, three of these panels can be welded together to form each half of the heat shield center section assembly. Subsequent welding of two center section halves and welding of closures to the ring member between the hinge supports at each of the six weld joints will complete the inner heat shield assembly.

The brazed honeycomb panels, located outboard of the center section and inboard of the corrugated heat shield structure would be the next panels to be welded to the center section assembly. Three different panel configurations must be used. A 1.5-inch thick honeycomb panel is located in the area of the six landing leg wells and between the hinges. A 1/2-inch thick panel is located outboard of this panel. These two panels, when welded in place, form the landing leg well cavity. The third panel configuration is 2 inches thick and occupies the area between the landing leg wells. All panel edge members will be welded to the braze assemblies after the braze operation. Panel preparation and edge member installation at the outboard panel edges will be deferred until all welding on the heat shield has been completed.

The sequence in which these outboard panels are welded to the center section main box structure, and to one another, is very critical. The assembly must be analyzed to determine a logical order to minimize weld shrinkage problems. It may be necessary to simulate the landing leg assembly with tooling to ensure proper location for each honeycomb panel. As shown in Figure 12 the two panels in the landing leg well area are welded together first to eliminate areas of weld shrink entrapment. Progressively, and in proper sequence, each honeycomb panel must be trimmed and welded into place.

Subsequent fabrication operations outboard of the honeycomb panel welded heat shield structure can follow procedures similar to those established for the Apollo aft heat shield assembly. The outboard panel edges will be trimmed and de-cored, and closeouts riveted in place. Corrugated panel subassemblies will be riveted to the panel closeouts, and the terminating seal ring member will be installed by riveting to the upper edge of the corrugated panels. All of these rivet operations, and the subsequent drilling of attach holes through the heat shield assembly, can be accomplished with existing Apollo tools.

Landing Leg Segment Fabrication

Because installation of the landing leg assemblies onto the aft heat shield will be the next operation performed, fabrication of the landing leg assemblies will be briefly discussed at this time. The assemblies shown in Figure 4 are designed as riveted, stiffened skin structures of PH 14-8 Mo corrosion resistant steel or equivalent. One "Y" shaped inner channel stiffener, one inboard and two side channel edge members, one outboard seal member, two hinge fittings, one strut attach fitting, one mold line skin, and eight angle stiffeners comprise the details required to fabricate each landing leg assembly. The most rigid and difficult member to form will be the "Y" shaped inner channel stiffener. To facilitate forming on drop hammer dies, this detail has been designed in two pieces with one weld toward the outboard end.

Progressive dies will be used to arrive at the final configuration. All forming and welding will be accomplished with material in the annealed condition, with subsequent heat treatment, straightening, and heat aging.

Each landing leg assembly can be fabricated in two stages as illustrated in Figure 12. Both of the hinge fittings and the one strut attach fitting will first be riveted to the "Y" channel utilizing an assembly fixture to hold each fitting in the proper location. Riveting of the outer mold line skin, panel edge members, and angle stiffeners to the initial internal assembly structure will complete the landing leg assembly.

Landing Leg System Installation

With the heat shield assembly in an inverted position, each landing leg assembly will be custom fitted to one of the landing leg wells. The two outboard explosive retainers for each landing leg assembly can also be temporarily installed, or simulated at this time, in order that mold line smoothness can be observed. Bolting of the landing legs in stowed position will be required for the next operations.

Fit check will still include bolting to the inner crew compartment and checking the interface of all mating components. Assuming the actuator brackets have previously been installed on the inner crew compartment, installation of the hydraulic cylinders will make it possible to check stroke clearance during deployment fit check of the landing leg assemblies. All structural work on the aft heat shield will be completed during this fit check operation. Upon completion of fit check, the aft heat shield, with landing legs again bolted in stowed position, will be removed from the inner crew compartment assembly in preparation for the installation of the ablator.

Ablator Installation

Ablator installation procedures will be basically similar to those now used on the existing Apollo aft heat shield. Honeycomb core will be bonded to the basic heat shield structures, followed by injection of the ablator into the core, and final grinding to the mold line configuration. Ablative application procedures similar to those used for Apollo heat shield access panels are employed where "no-bond" members must be installed around the periphery of each landing leg assembly to allow proper deployment. In addition, ablative failure plugs, also surrounded with "no-bond" members, are required in the area of the landing leg hinge arms. These plugs will be removable for checkout of the entire landing system upon completion of the ablator installation. Although some development work is anticipated for these areas containing ablative separation requirements, AVCO, fabricator of the Apollo ablative heat shield, considers the concept feasible.

Installation on Crew Compartment Structure

Final installation of the aft heat shield on the inner crew compartment should require no additional structural effort, because of the initial fit-check operation. After being bolted to the inner crew compartment, the attenuation struts and lines can be connected for a landing system checkout. This will be done with the ablative failure plugs removed from beneath each of the landing leg hinge arms. After the deployment checkout, the landing legs will be secured in stowed position with the explosive retainer nuts and failure plugs replaced. The last operation will be the final attachment of the bellows between the attenuator struts and landing leg assemblies.

EVALUATION OF RADIAL SKID CONCEPT

DESIGN CHARACTERISTICS

The design of this system encompasses the use of a deployable aft heat shield and a series of radially extendable landing skids to prevent rolling or overturning of the command module. For the specified range of landing attitudes given in the Guidelines, Constraints, and Design Criteria section, the skids do not contact the ground at initial impact. They do make contact when the spacecraft tends to tip over, and prevent its overturning. The forces applied to the spacecraft at landing impact are attenuated by shock absorbers located between the deployable heat shield and the inner body structure. The horizontal forces are absorbed by friction of the heat shield sliding over an unprepared landing surface.

Functionally, this system design is very similar to Concept 5260-2, previously discussed in Reference 1. Specifically, it differs in the number of attenuators used for vertical forces, the deployed length of the radial skids, and the incorporation of folding braces to resist the lateral loads due to the friction on the heat shield.

A preliminary reevaluation of the original design had shown that a significant weight reduction could be made in the impact attenuation and skid structure while satisfying the established design criteria summarized in the Guidelines, Constraints, and Design Criteria section.

Structural System Description (Figures 13 and 14)

The structural hardware of this concept consists of a command module heat shield modified to include 12 light-weight rectangular steel tubes within individual rectangular housings. An inner and an outer support ring complete the primary framing of the honeycomb heat shield. A series of tension studs and separation nuts in the same location as the Apollo tension bolts attach the heat shield to the inner body. Also attached to the heat shield are six combination actuator/attenuator struts located in the vertical plane at 60-degree intervals. The aft end of each shock absorber is attached to the heat shield outer support ring, while the forward rod end is connected to the inner body support. This forward end incorporates a threaded adjustment for final position length. Spherical bearings in both ends provide compensation for angular misalignment. Heat shield inner body lateral movement or

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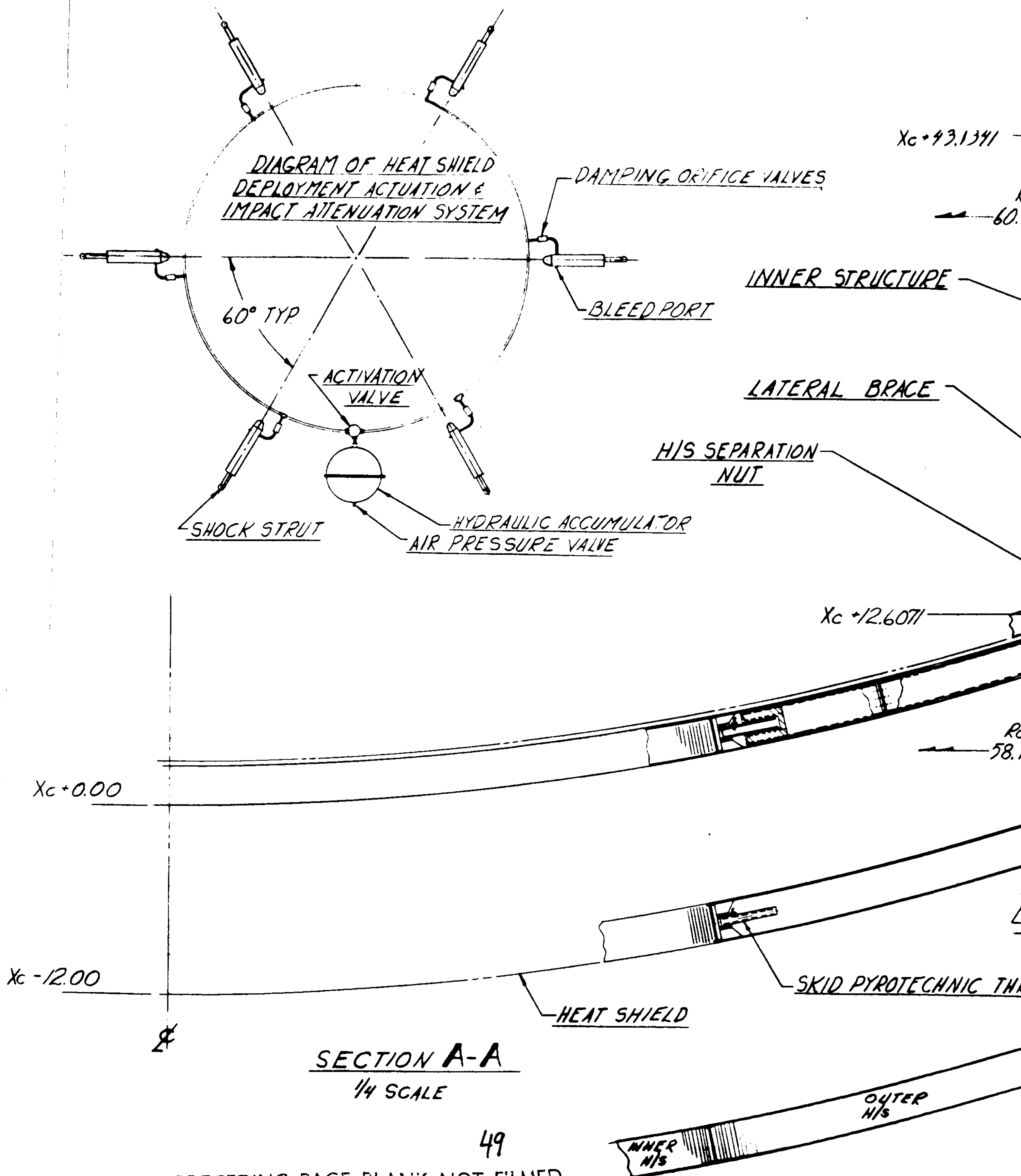
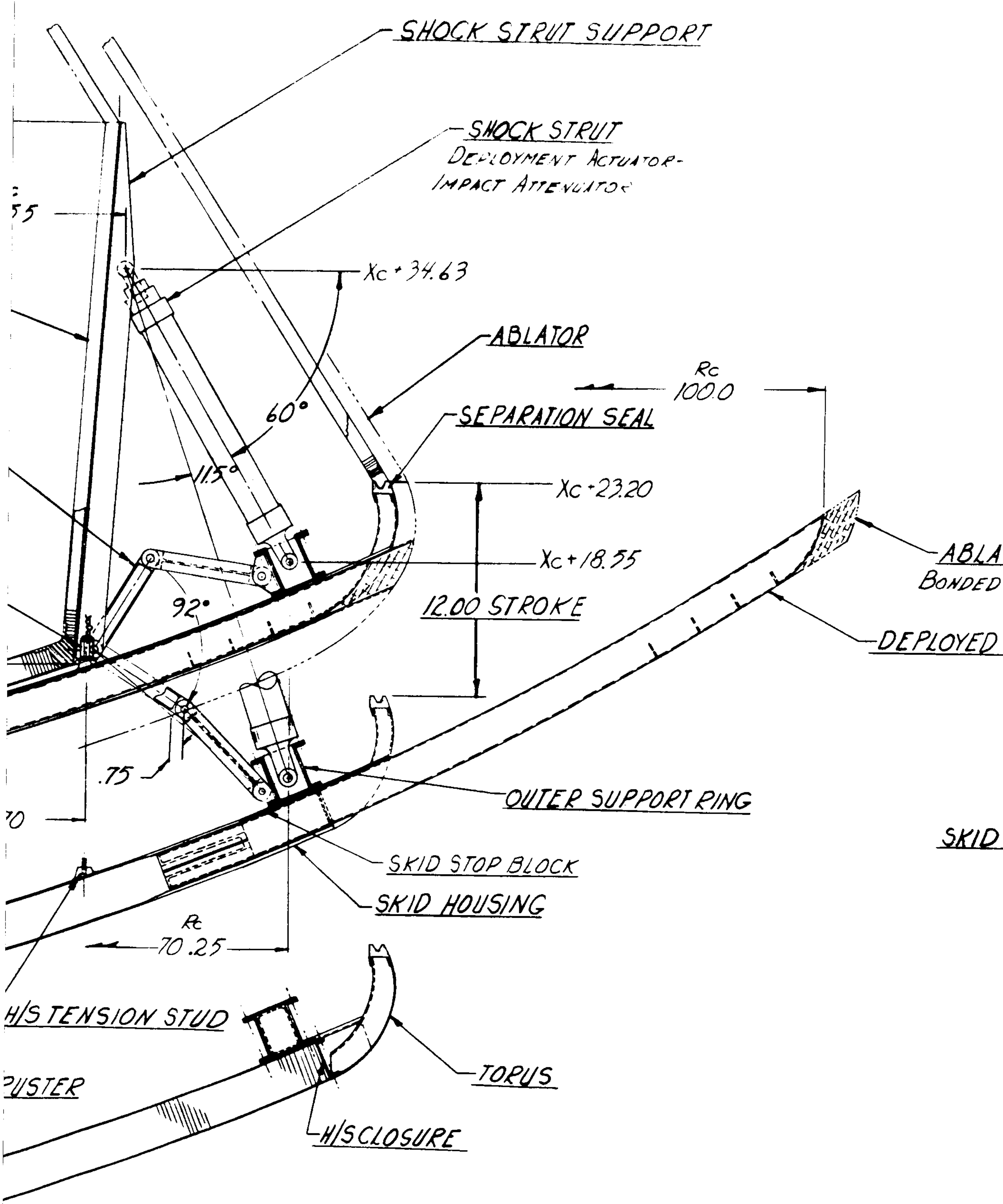
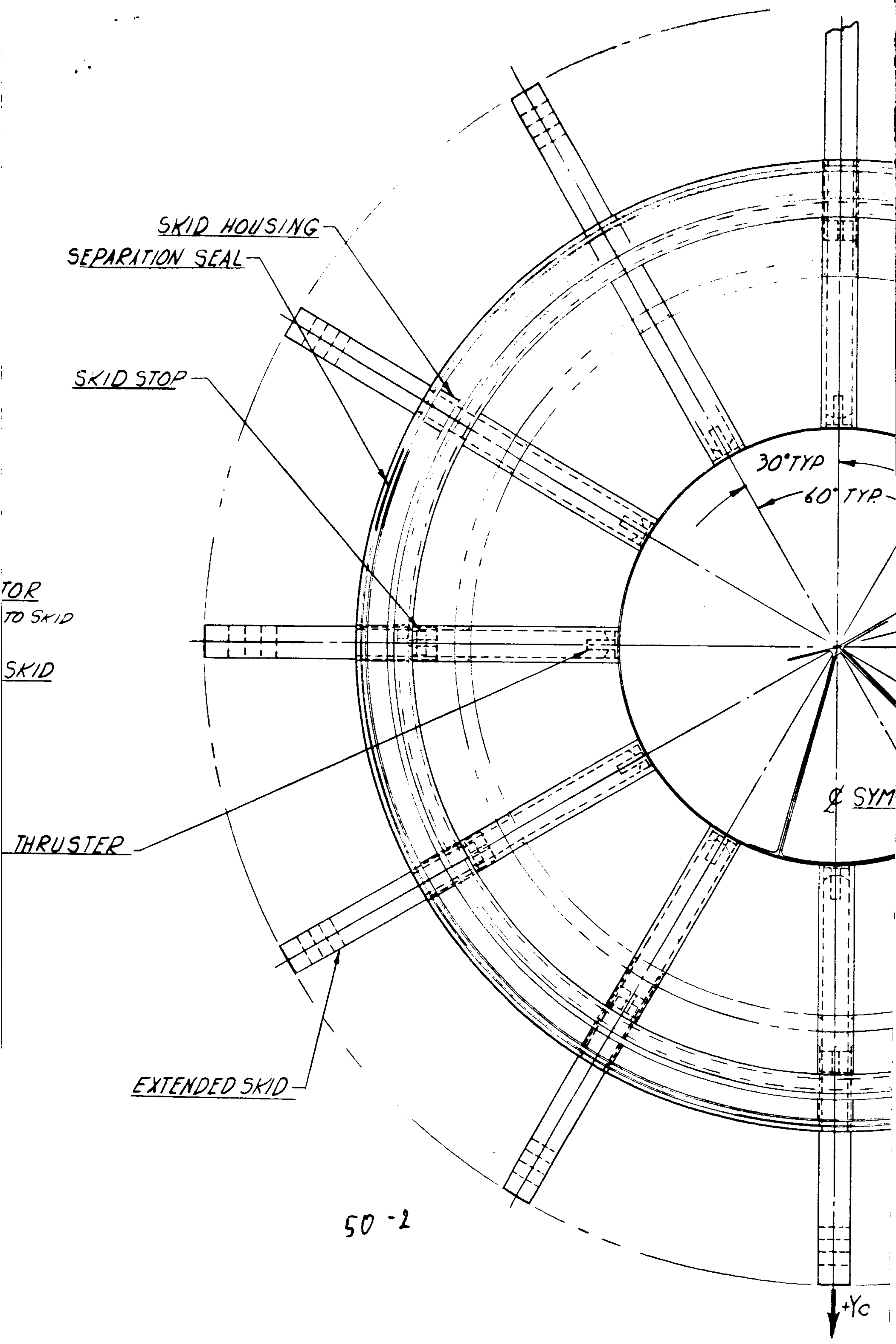


SECTION A-A
1/4 SCALE

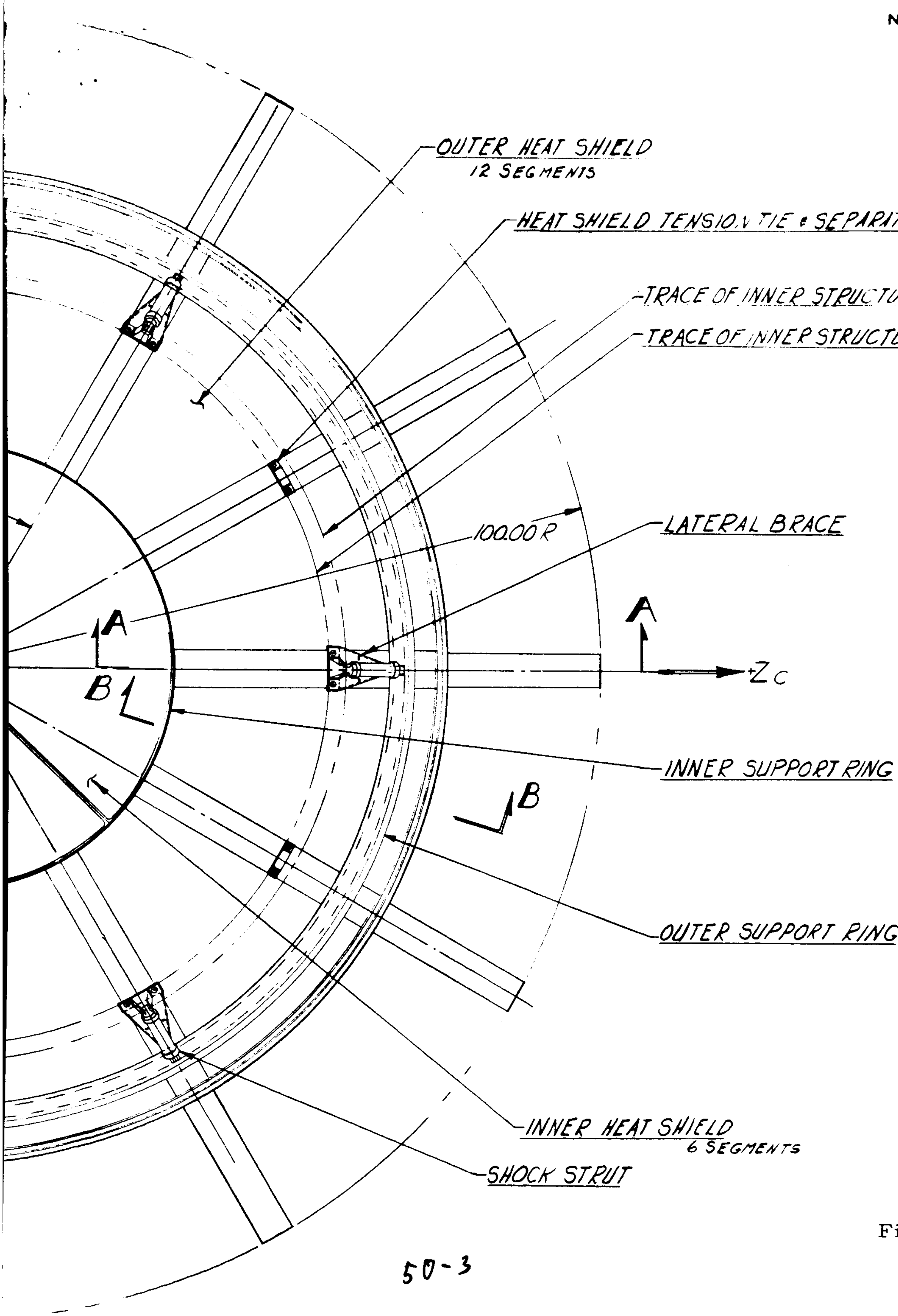


SECTION B-B
1/4 SCALE

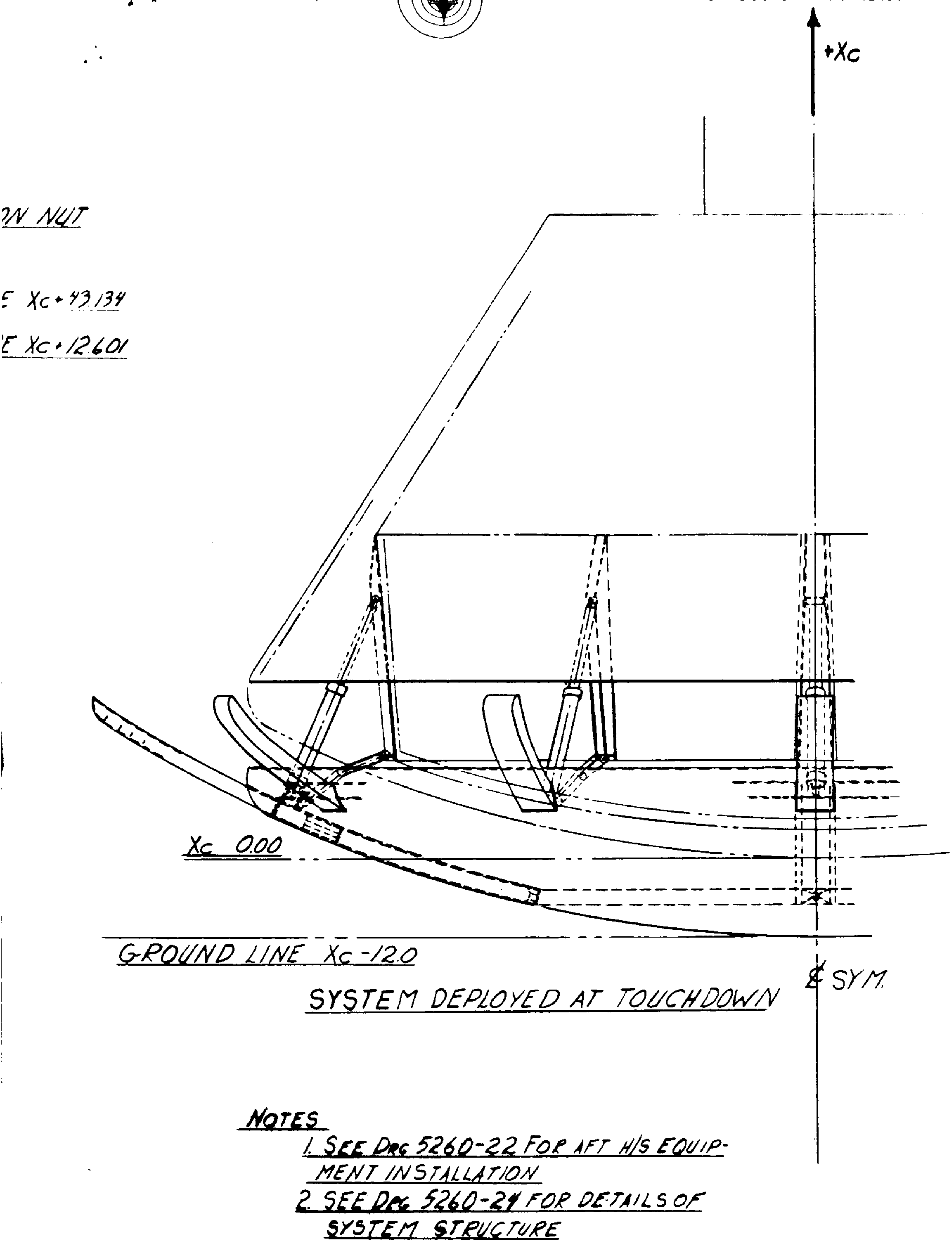


SKID HOUSING
SEPARATION SEAL
SKID STOP
TOR
TO SKID
SKID
THRUSTER
EXTENDED SKID
30° TYP
60° TYP
℄ SYM
+Yc

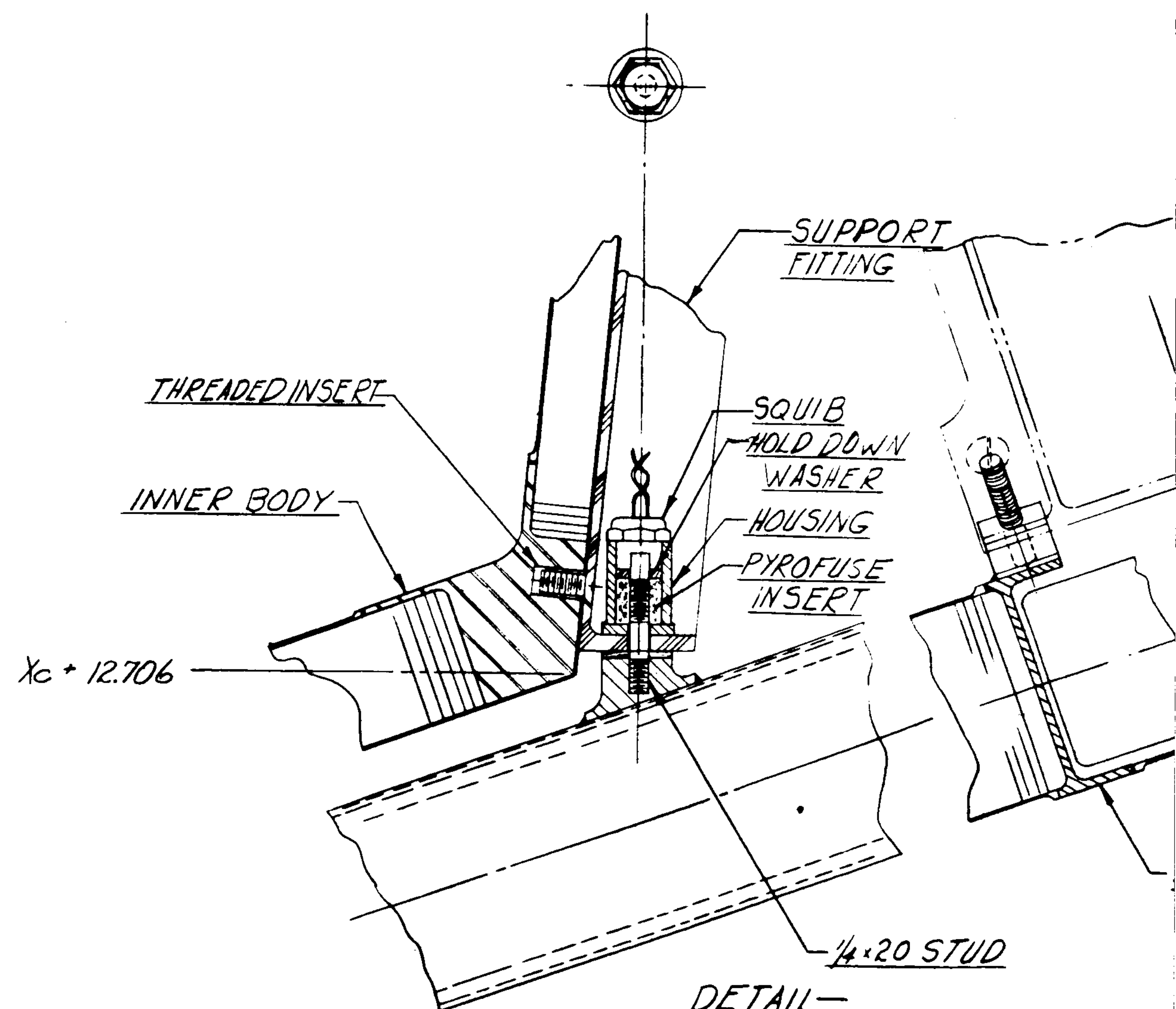
NO


OUTER HEAT SHIELD
12 SEGMENTS
HEAT SHIELD TENSION TIE & SEPARATI
TRACE OF INNER STRUCTUR
TRACE OF INNER STRUCTUR
LATERAL BRACE
100.00 R
A
B
A
Z_C
B
INNER SUPPORT RING
OUTER SUPPORT RING
INNER HEAT SHIELD
6 SEGMENTS
SHOCK STRUT

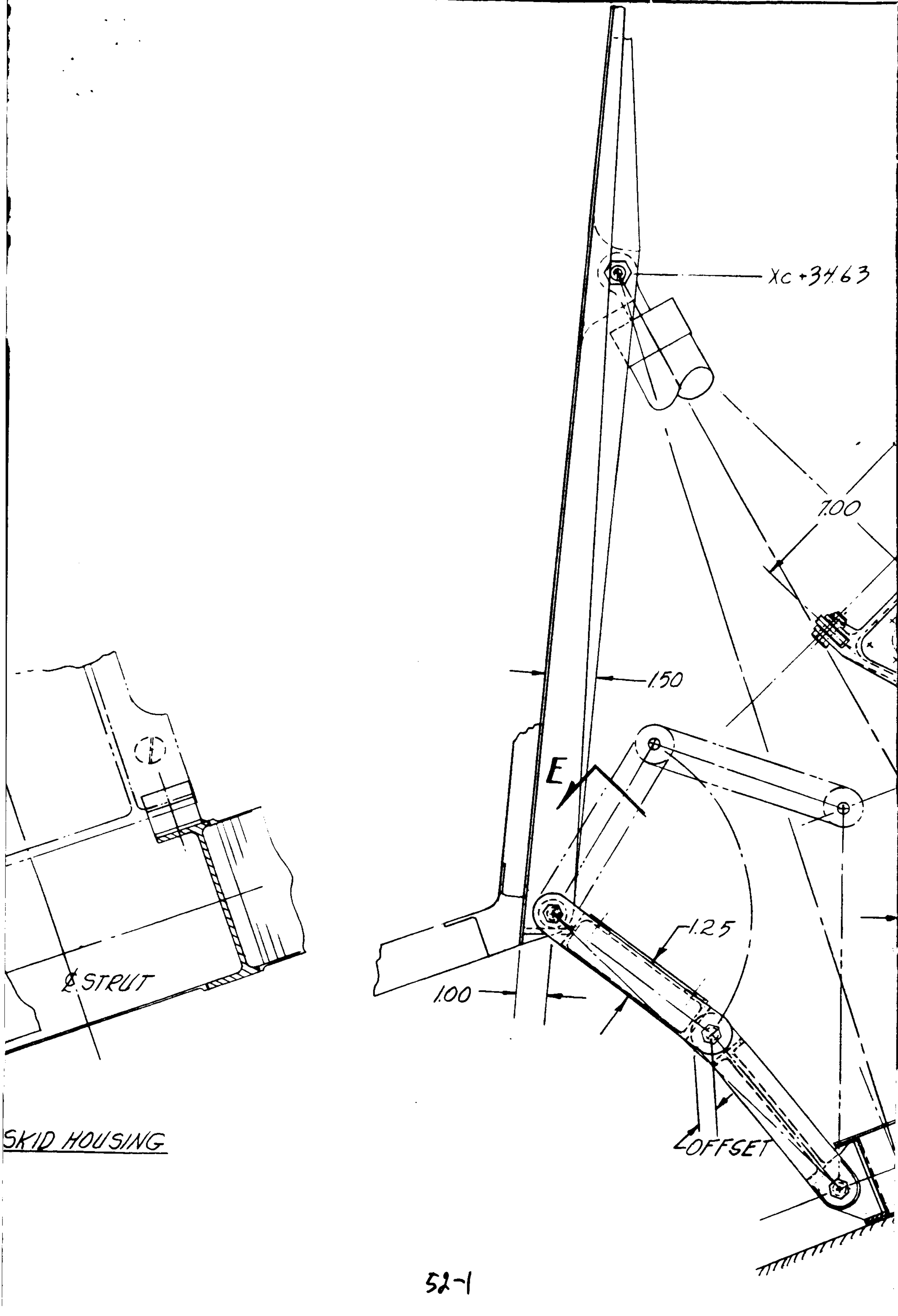
Fig



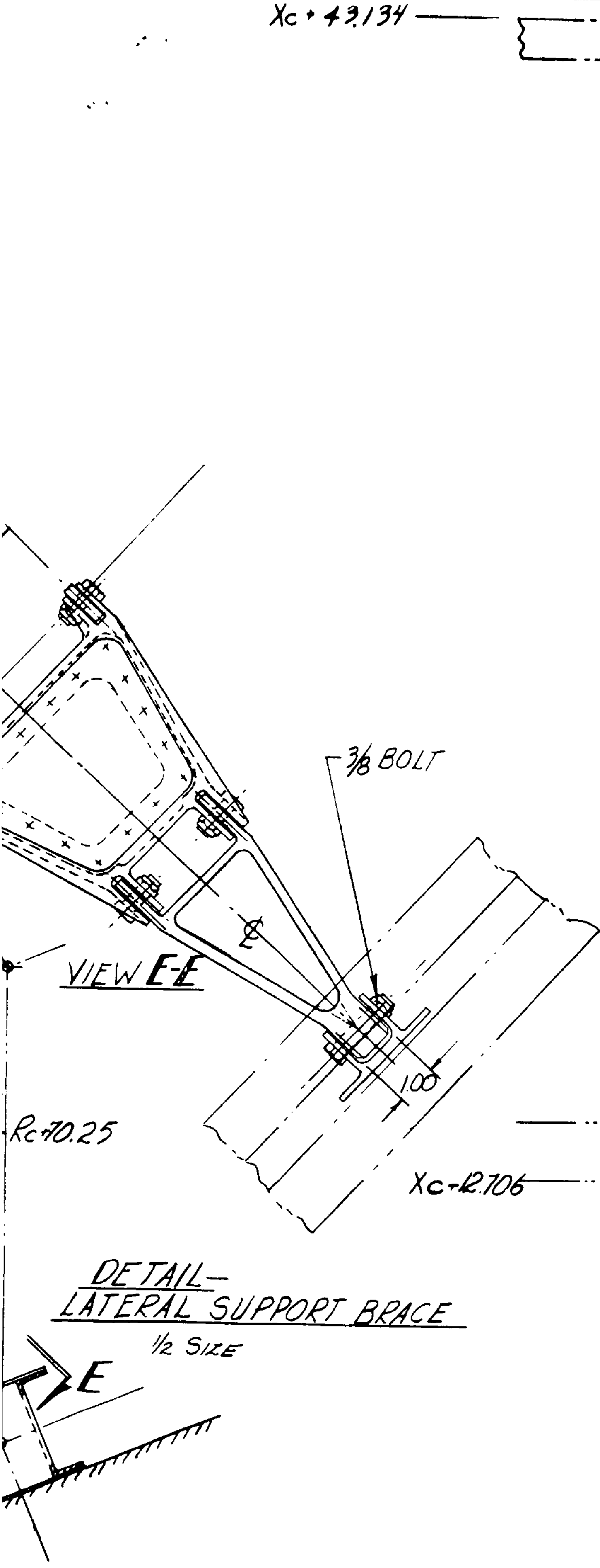
ure 13. Deployable Heat Shield With Radially Extended Skids MISDAS Study



DETAIL—
HISTENSION TIE &
SEPARATION NUT
FULL SIZE

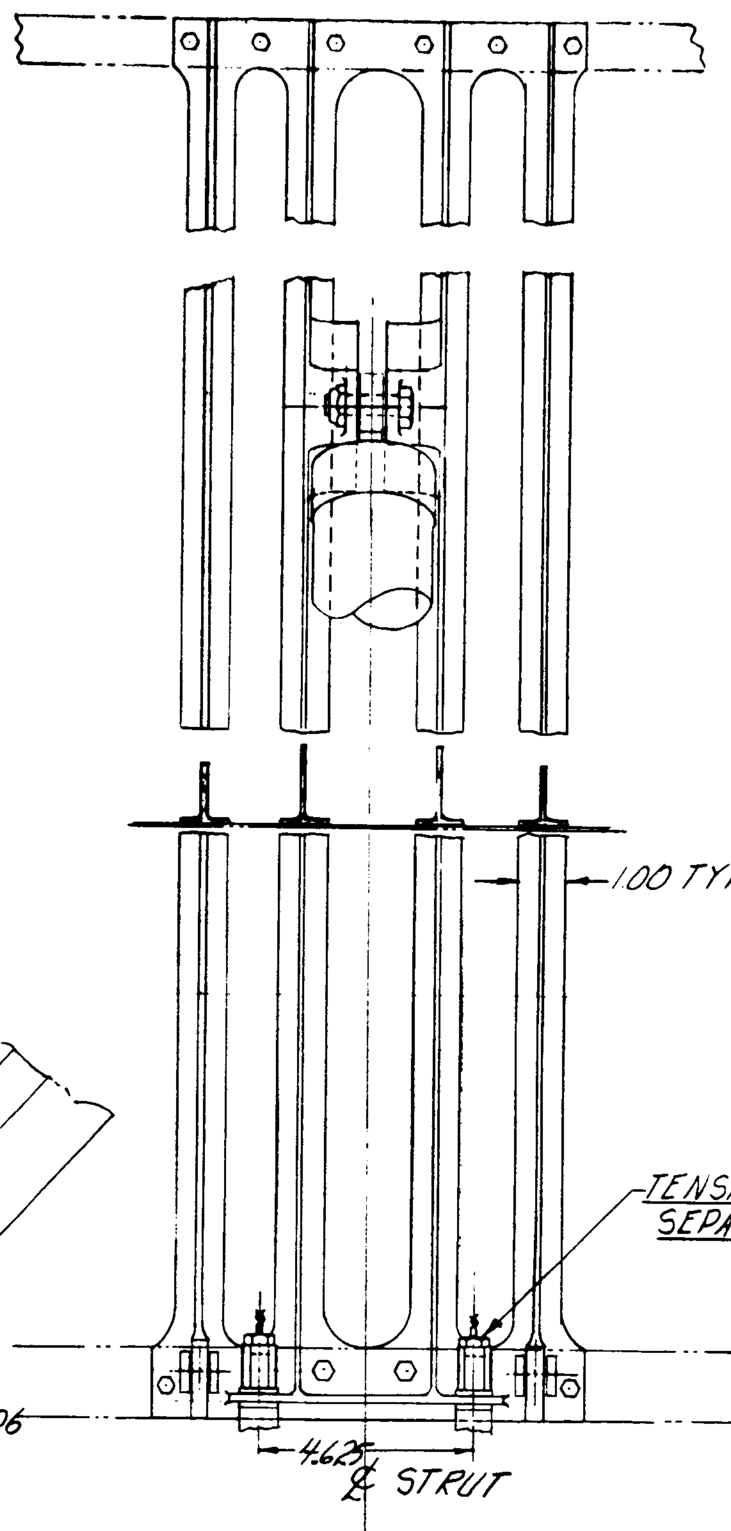


XC +34.63
7.00
.150
E
1.25
1.00
OFFSET
₵ STRUT
SKID HOUSING



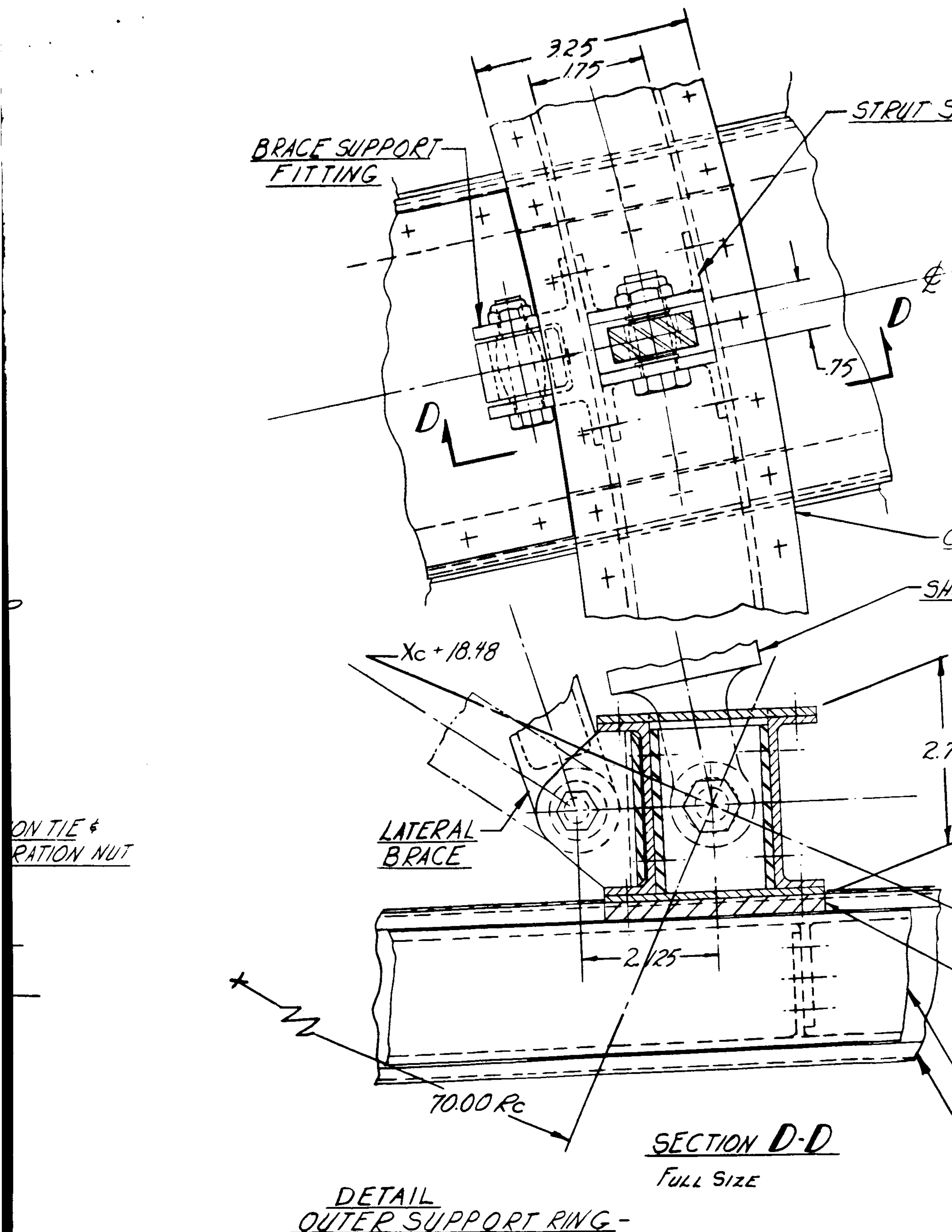
DETAIL-
LATERAL SUPPORT BRACE

1/2 SIZE



DETAIL-SUPPORT FITTING
SHOCKSTRUT, LATERAL BRACE & TENSION TIE

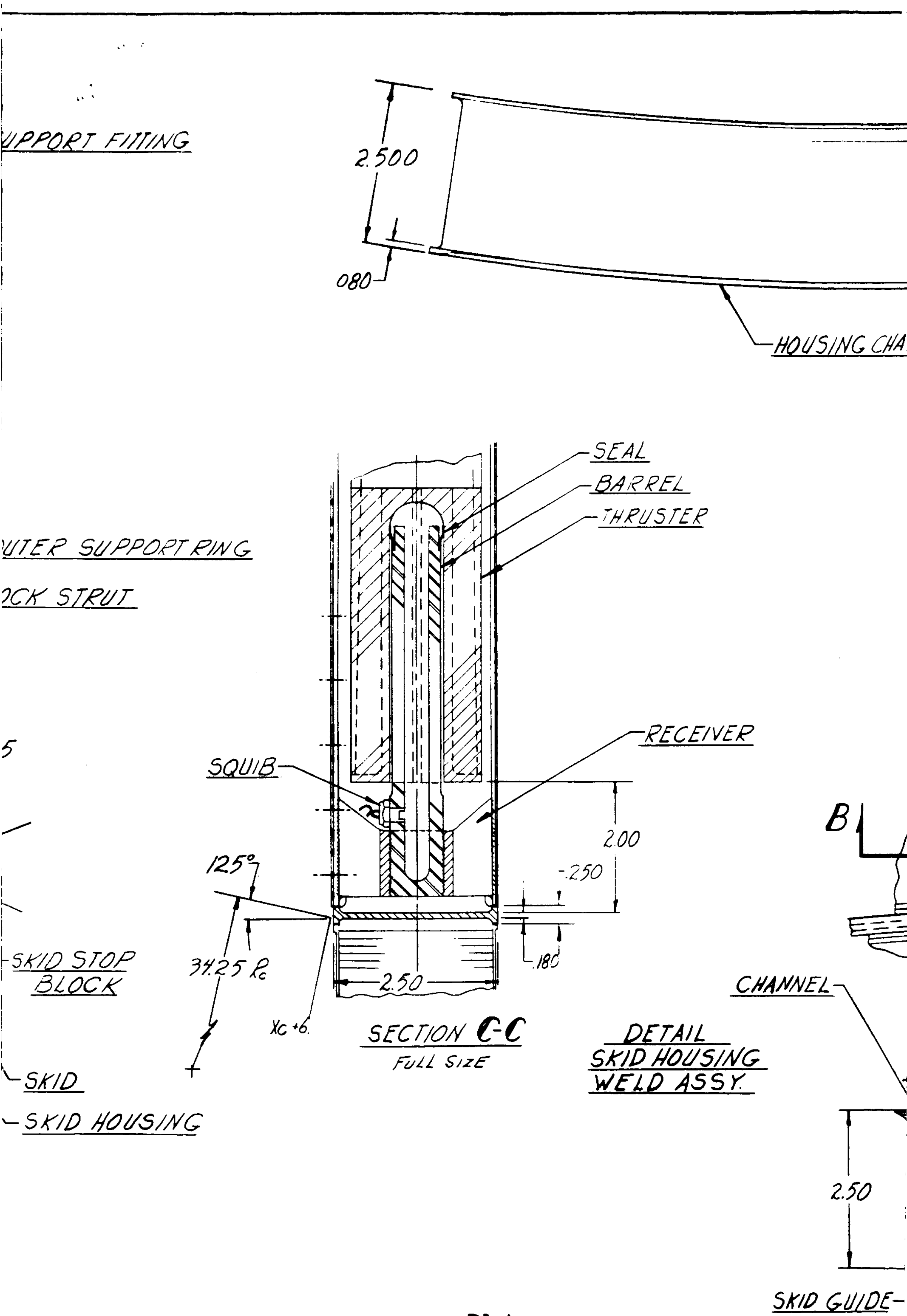
1/2 SIZE

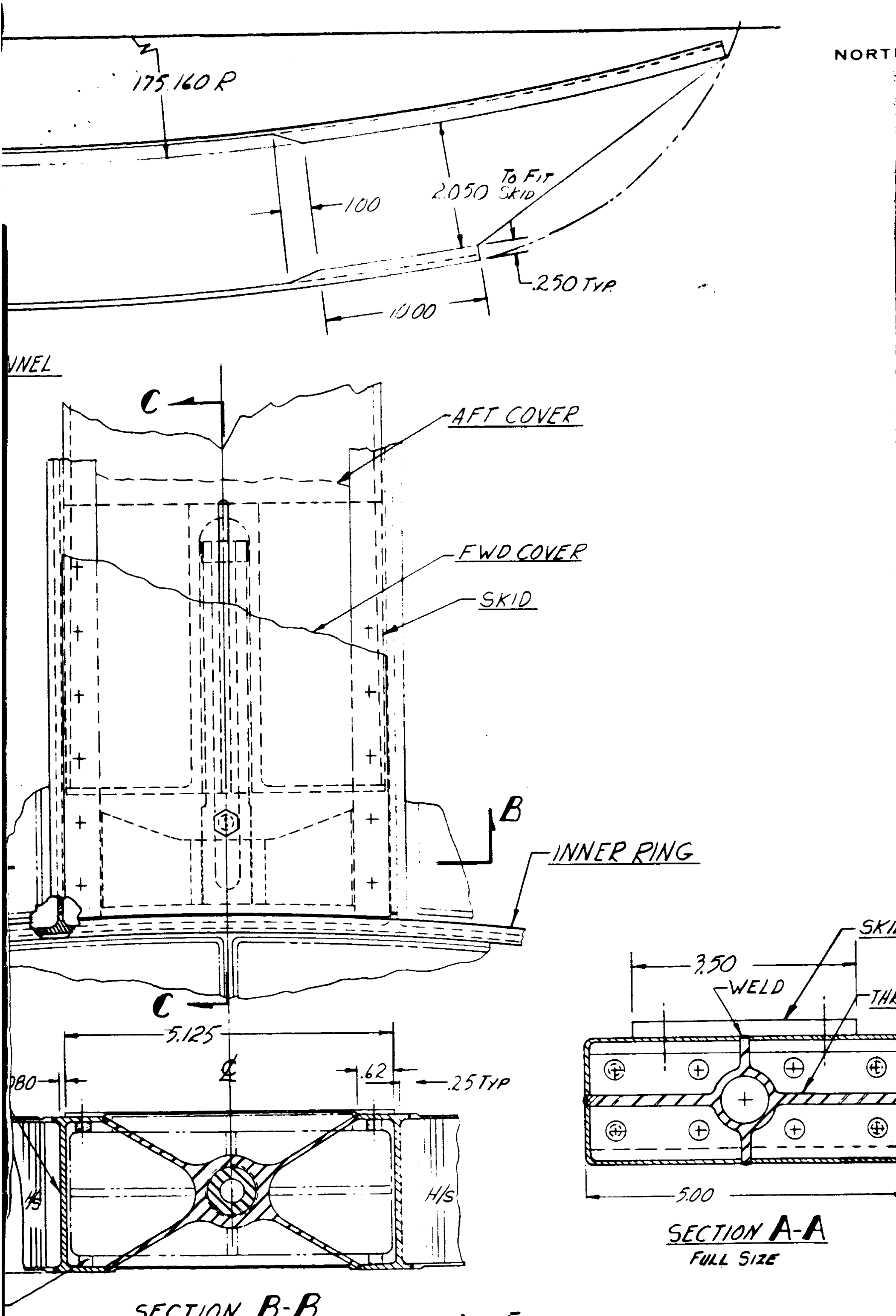


SECTION D-D

FULL SIZE

DETAIL
OUTER SUPPORT RING -
BRACE & STRUT SUPPORT FITTINGS


SUPPORT FITTING
2.500
080
HOUSING CHA
OUTER SUPPORT RING
OCK STRUT
SEAL
BARREL
THRUSTER
RECEIVER
SQUIB
5
2.00
-.250
12.5°
34.25 Rc
.180
2.50
Xc +6.
SKID STOP BLOCK
SKID
SKID HOUSING
SECTION C-C
FULL SIZE
DETAIL
SKID HOUSING
WELD ASSY.
B
CHANNEL
2.50
SKID GUIDE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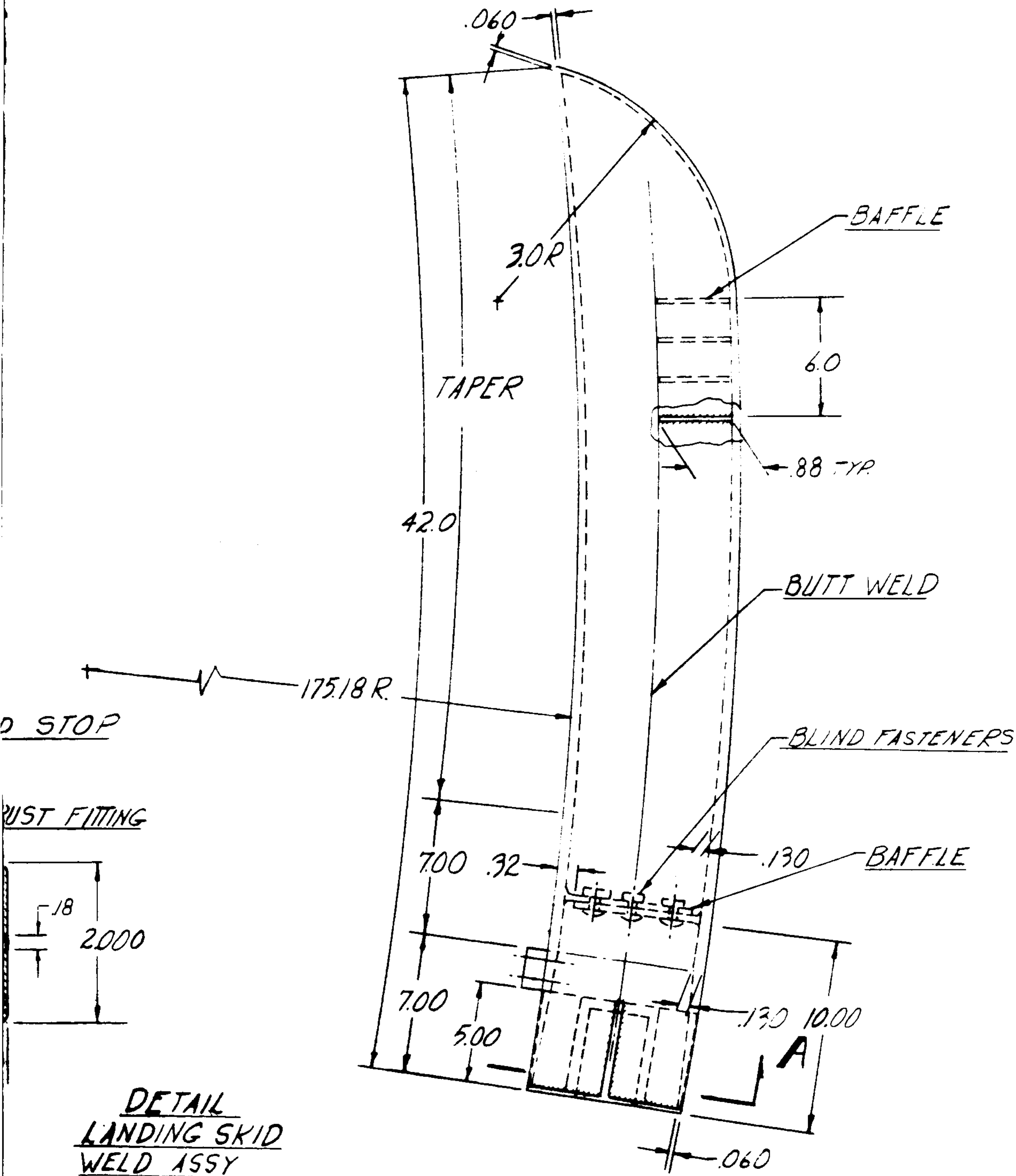


Figure 14. Structure Details Deployable Heat Shield - MISDAS

horizontal rotation is resisted by six folding braces (torque scissors) between the inner body supports and the outer support ring, located directly below the six shock absorbers.

System Operation

Sequentially, the deployment of the landing impact system follows the landing signal, with the release of the heat shield tension tie. An electrically initiated set of squibs within the separation nuts activates a structural pyro-fuse insert by high temperature which releases the tension stud. A pressure-charged hydraulic accumulator is then activated to pressurize and extend the shock absorber struts. The accumulator maintains pressure in the shock struts, permitting them to absorb impact energy by flow of oil through the damping orifices. In sequence or concurrent with the heat shield extension, electrically initiated squibs activate the pyrotechnic thrusters in the skids and propel them radially through the skid housings. The skids are stopped and locked in their extended position with sufficient overlap provided for socket action to resist the bending moment from the loads on the outer portion of the skid during landing. Associated electronic and mechanical units complete the systems and integrate the sequencing sections into a highly reliable and efficient ground landing system. Components similar to those used for airplane jettison systems and canopy and seat ejection could be developed for the skid extension. Thus, the concept is considered technically feasible.

Spacecraft Compatibility

The command module inner body will require the modifications shown in Figure 15 to accommodate the landing impact system. A number of systems and associated components within the aft heat shield compartment as identified on page 54, will require relocation and refitting for space and operating accommodations. The additional support structure will have to be added and located on the outer walls of the inner body for structural continuity. The tension ties between the command module and service module do not require structural redesign. Minor modifications to equipment and fittings in the reduced clearance space between the command module floor structure and heat shield may be required. These changes are described in the following section.

MISDAS/AES/RETROROCKET INTEGRATION

For purposes of these final configurational arrangements, the design concept using four modified Gemini retromotors, selected by NASA for AES, was utilized for vertical descent retardation. A new structural mounting concept and motor nozzle configuration was used although the AES motor case configuration was retained.

In no case does the relocation of equipment introduce any significant thermal problem. Effects on the spacecraft center of gravity and inertia were included in the analysis summarized in Table 8. Effect on stability in flight and landing conditions was negligible.

Packaging Considerations

This concept (Figure 15) illustrates a gross packaging arrangement of the four retromotors, the subsystem components, the torque links, and skid deployment cylinders in the aft equipment bay. The 12 radial skid assemblies are positioned symmetrically in the aft heat shield with the plane of two skids on the Zc-axis. The structural and mechanical details of the deployment system for the radial skid deployable heat shield concept are shown in Figure 13. The four retromotors are unsymmetrically located 28 and 40 degrees either side of the +Zc-axis and 22 degrees either side of the -Zc-axis.

Installation of the four retromotors, shock struts, and torque links in the aft compartment equipment bay of the command module will require the following relocation of subsystems and aft compartment frames:

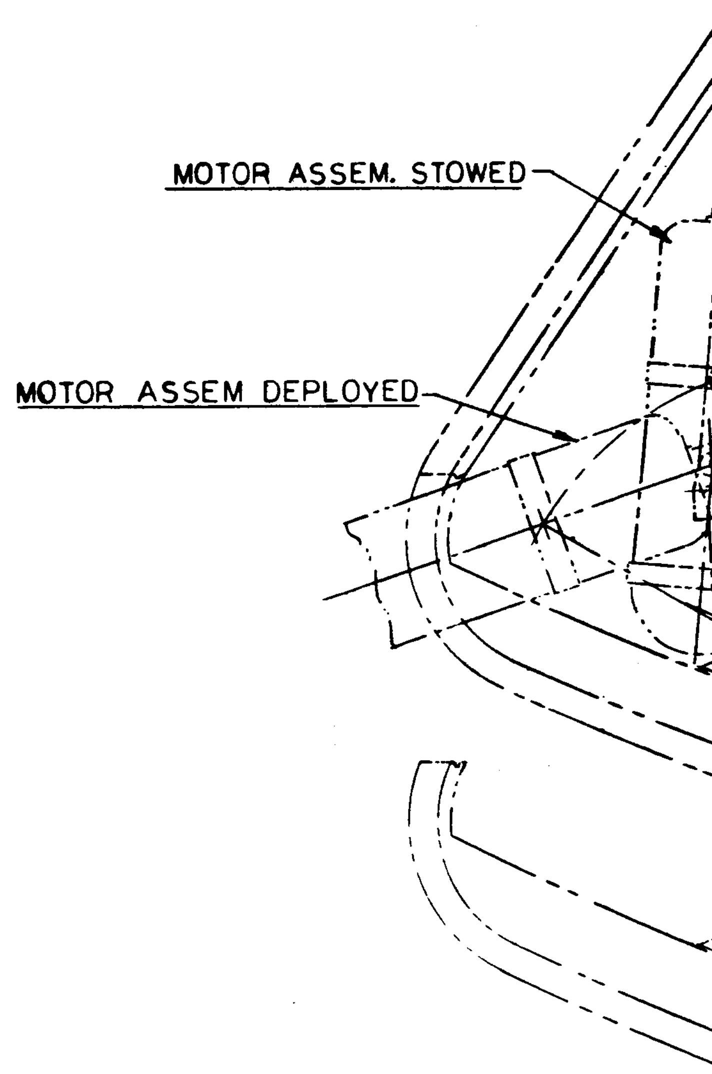
1. The uprighting system compressor and the helium tank between Frames 1 and 2, and the RCS switches were repositioned between Frames 19 and 20 to allow space for installation of the structural and mechanical details of the skid deployment system between Frames 2 and 3.

2. The oxidizer tanks, waste water tanks, and fuel tanks between Frames 4 and 11 must be repositioned between Frames 3 and 4 and between Frames 19 and 20 to accommodate the installation of the structural and mechanical details of the skid deployment system between Frames 5 and 6 and between Frames 10 and 11.

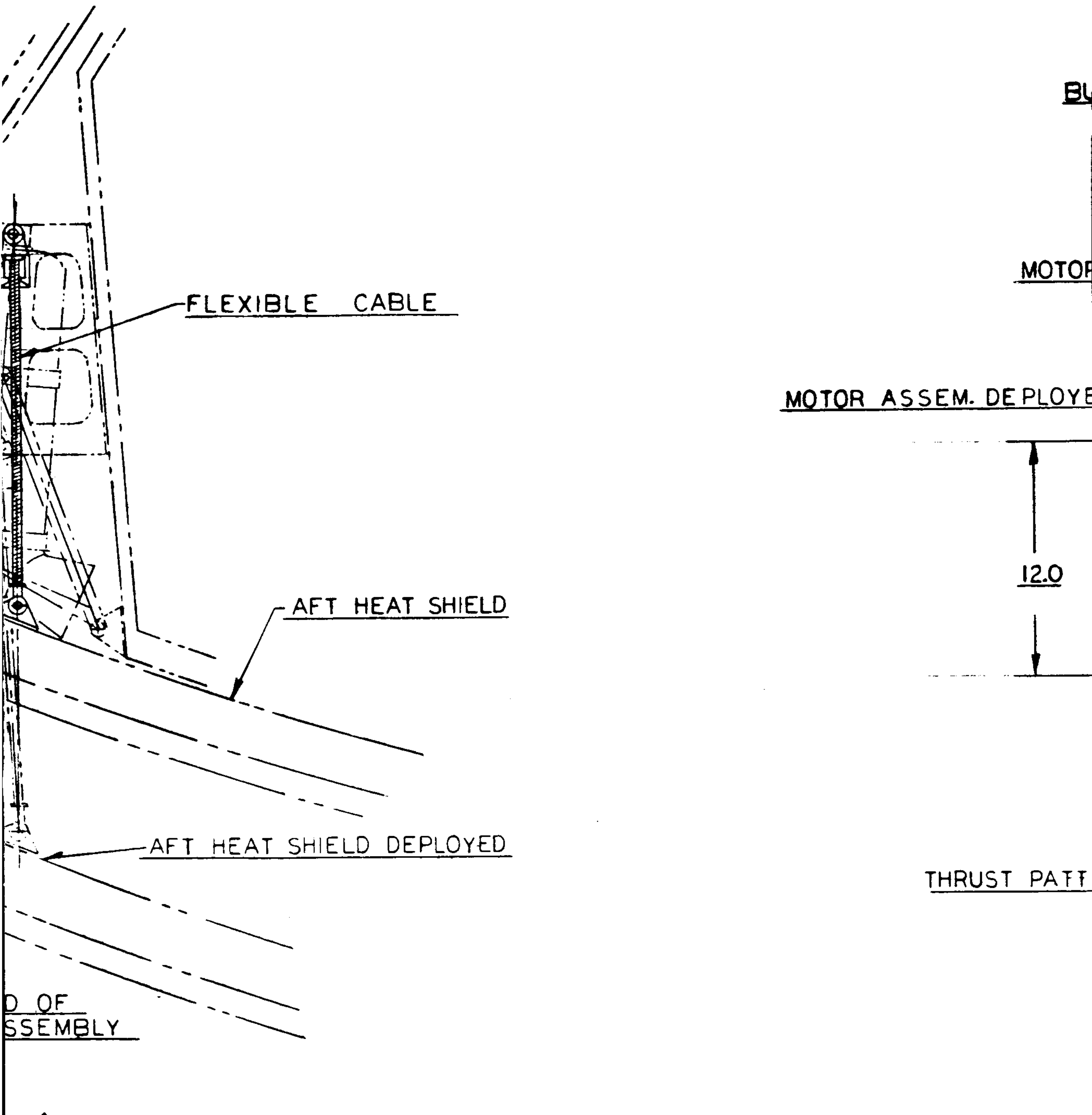
3. The structural and mechanical details of the skid deployment system located at Frames 15 and 22 require redesign and modification of the roll RCS engine support structure. The steam vent requires repositioning to a location between Frames 17 and 18.

4. The pitch engines between Frames 18 and 19 must be repositioned due to the structural and mechanical details of the skid deployment system located in this area.

5. The aft compartment Frames 5, 7, 17, and 20 must be redesigned to accommodate installation of the retromotors located at these positions.



ALTERNATE METHO
DEPLOYING MOTOR A



BU
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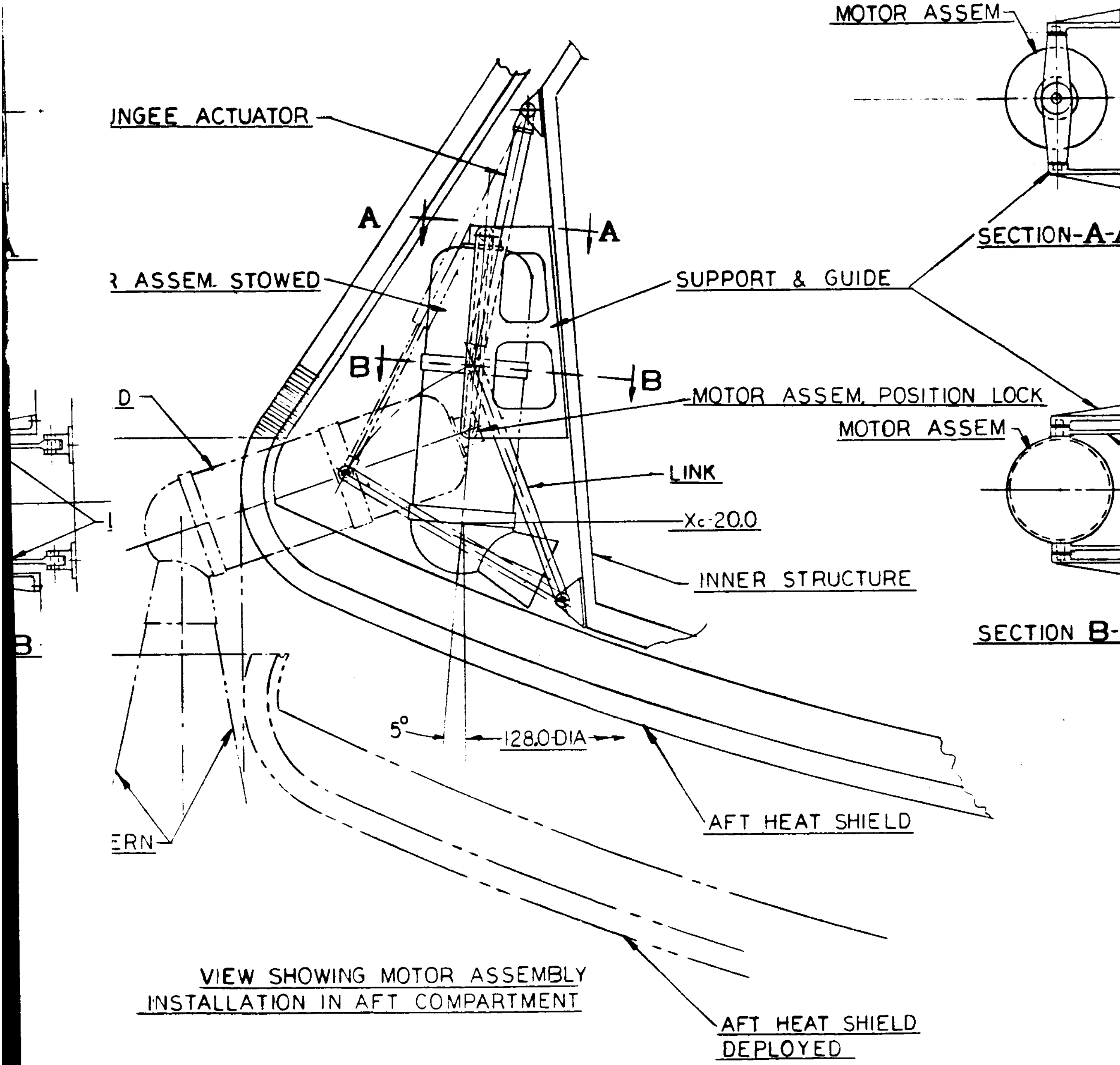
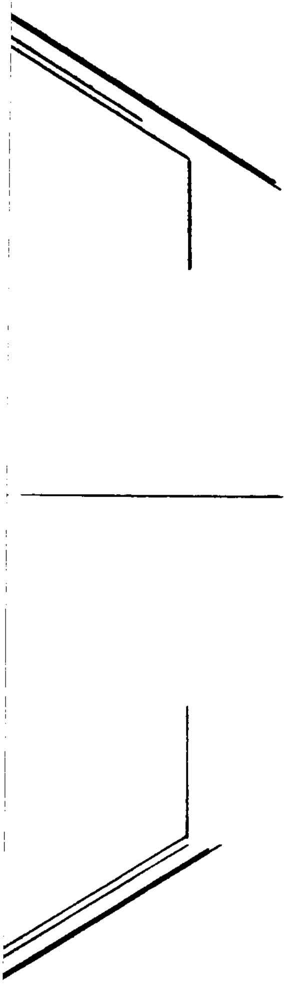


VIEW SHOWING MOTOR ASSEMBLY INSTALLATION IN AFT COMPARTMENT

LOYMENT CYLINDER



1. OXIDIZER TANK - 2
2. WASTE WATER TANK
3. FUEL TANK - 2
4. HELIUM TANK - 2
5. POTABLE WATER TANK
6. YAW RC ENGINE - 4
7. ROLL RC ENGINE - 4
8. PITCH RC ENGINE - 2
9. RELIEF DUMP VALVE
10. STEAM VENT
11. HELIUM PRESSURE PANEL - 2
12. FUEL CONTROL PANEL
13. ELECTRICAL UMBILICAL
14. OXIDENT CONTROL PANEL
15. RCS MOTOR SWITCH
16. AIR VENT
17. UPRIGHTING SYSTEM COMPRESSOR
18. TENSION TIE - 3
19. RCS CONTROL PANEL

NOTE

FOR RADIALLY EXTENDED SKIDS INSTALLATION SEE DRG № 5260-17

R ASSEM.

igure 15. Retro-Motor Assembly Installation Deployed Heat Shield Concept MISDAS Study

6. The electrical umbilical may require rearrangement to be compatible with the modifications previously noted.

Retromotor Installation

Initial studies of the problems associated with installation of the retromotors and a fully deployable heat shield indicated the following possible arrangements:

1. Retromotors structurally attached to the heat shield that move with the heat shield upon deployment.

2. Retromotors structurally attached to the command module inner structure sidewall in the aft equipment bay. An extendable motor nozzle shroud would be required to serve as a conduit for the motor exhaust from the fixed nozzle position to the exhaust port in the deployed heat shield, 12 inches below the motor nozzle.

3. Retromotors supported off the command module inner structure sidewall. The motors would rotate outward through the space provided by dropping the heat shield and fire downward from the periphery of the base of the vehicle.

The primary disadvantages of the first approach is that the high thrust level of the four motors (approximately 40, 000 pounds total) would require locking out the stroking capability of the shock struts during the retrothrusting phase, then unlocking to permit mechanical stroking and attenuation. This operation would be extremely time-critical because of the short interval between retromotor firing and ground touchdown. Reliability of the lock/unlock system would be doubtful.

The design and operational problems associated with providing the extendable nozzle in the second approach make this concept unfavorable.

The third approach was selected as the easiest from the standpoint of design and development. This concept can achieve the highest reliability since it avoids any requirement for heat shield exhaust ports and ejectable plugs.

A retromotor support and guide bracket attached to the outer surface of the inner structure forms the basic support for the retromotor. The retromotor is installed through a door provided in the outer wall of the aft

compartment. At the forward end of the retromotor, a trunnion with rollers provides the guidance of the motor to the deployed position. A link attached to the lower corner of the inner structure and to the midstation of the motor drives the motor to the outboard position. Two alternate methods of actuation are shown. One method is by a hydraulic or spring bungee and the other is by a cable attached to the head of the retromotor and to the deployable heat shield. The cable fitting at the head of the retromotor is designed to allow 1 inch of free travel before the deployable heat shield extends the retromotor. This is necessary because the stroke to position the motor is 11 inches and the heat shield deploys 12 inches. The retromotor in the deployed position is located so that the motor exhaust will clear the deployed heat shield.

A lock at the extreme lower end of the guide grove in the main support bracket is provided to secure the motor in its deployed position.

STRUCTURAL ANALYSIS

The installation of the radial-skid MISDAS concept in AES was subjected to structural and deflection analyses to check the feasibility of the installation. The major components of the attenuation system and affected parts of the AES heat shield and command module inner structure were considered. Objectives of the analysis were to determine critical conditions, select materials, calculate member sizes, provide a basis for mass property analysis, and assure the integrity of the command module inner structure. The analyses are based on Figures 12 and 13, using the design criteria specified in the Guidelines, Constraints, and Design Criteria section. The primary load paths are shown in Figure 16, and the principal results are summarized in Table 5. The complete stress analysis is presented in Appendix A of this report. The materials considered and their structural properties are discussed in Appendix C. The major aspects of the structural study are discussed in the following paragraphs.

Critical Conditions

The critical design conditions are ground impact, skid contact, water impact and boost abort. The ground impact condition designs the shock struts and their attachment fittings to the inner structure. For the selected geometry, the skids do not hit the ground at initial impact. Skid contact occurs when the spacecraft rocks a sufficient distance for the deployed skid to touch the ground. This condition is critical for design of the outer box section ring at a 71-inch radius, the inner ring, the skid housing, and the skids. The water impact condition is applicable to design of the honeycomb core and face sheets of the aft heat shield substructure. The boost abort load designs the attachment of the aft heat shield to the inner structure.

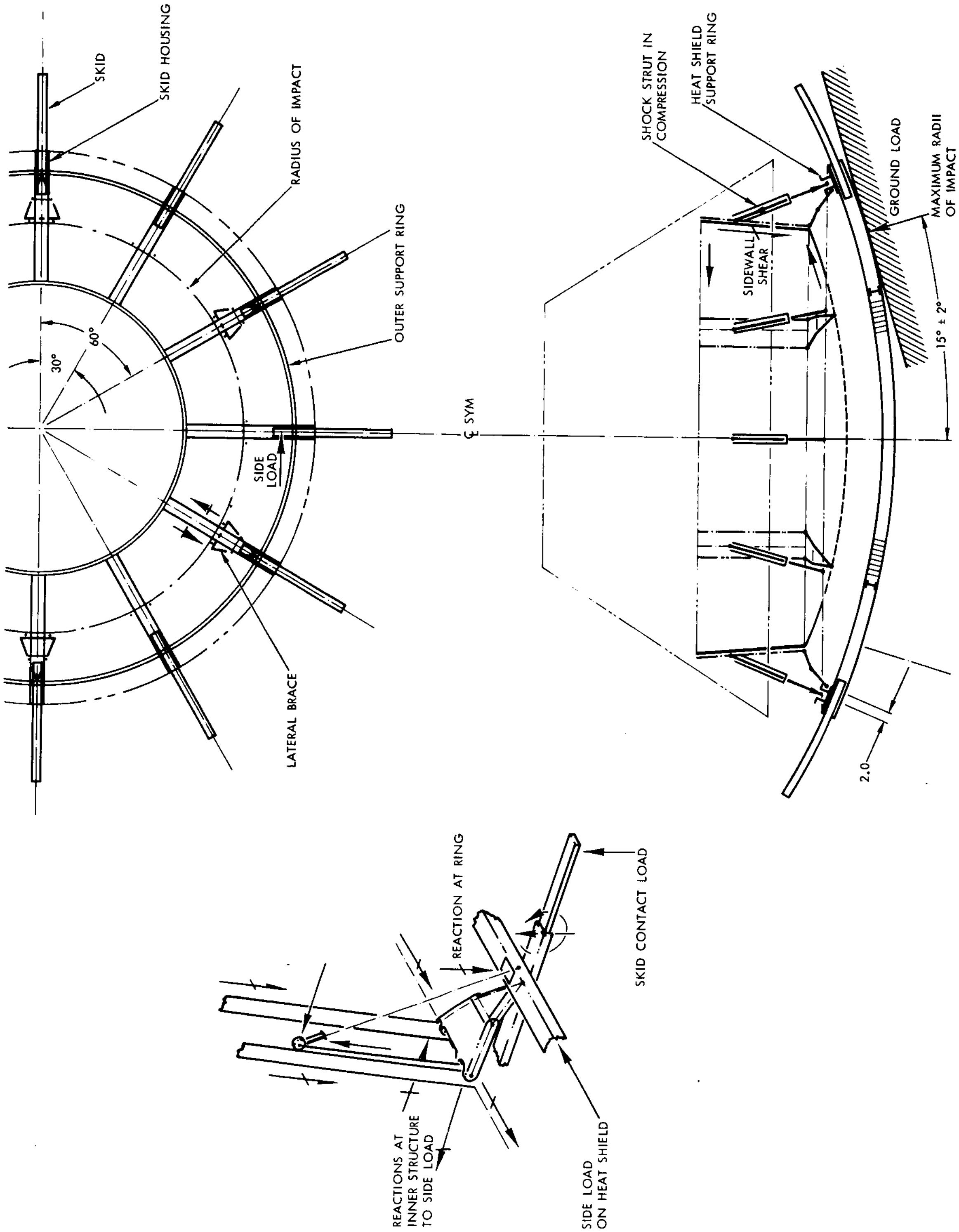


Figure 16. Structural Diagram, Deployable Heat Shield System

Table 5. Critical Stresses and Margins of Safety - Radial Skid Concept

Item	Typical Material	Size	Critical Condition	Stress (psi)	Allowable Stress (psi)	Margin of Safety	Design Factor of Safety
Aft heat shield skin	Steel PH14-8	t = 0.018 to 0.008	Water impact	135,000	135,000	0.00	1.00
Aft heat shield core	Steel PH14-8	3/16 cell, 0.0015 foil	Water impact	515	860	0.67	1.00
Skid	Steel PH14-8	t = 0.120	Skid contact	81,000	101,000	0.37	1.00
Skid housing	Steel PH14-8		Skid contact	198,000	230,000 bending modulus	0.16	1.33
Heat shield inner ring (34R)	Steel PH14-8		Skid contact	98,500	156,000	0.56	1.33
Heat shield outer ring (71R)	Steel PH14-8		Skid contact	138,000	156,000	0.13	1.33
Support fitting	Aluminum alloy 7075-T6		Ground impact	58,300	60,000	0.03	1.33
Side load links	Aluminum alloy 7075-T6		Ground impact	48,000	54,000	0.09	1.33
Inner structure aft sidewall skin	Aluminum alloy 2014-T6	t = 0.016	Ground impact	29,500	38,000	0.29	1.33
Inner structure aft sidewall skin to ring bond	Epoxy adhesive		Ground impact	630	1,320	1.10	1.33
Shock strut	Steel PH14-8		Ground impact	87,000	96,000	0.10	1.33

Assumptions

The loads and criteria in the Guidelines, Constraints, and Design Criteria section are consistent with ARM-6 (Reference 5) with the following exceptions: The water impact condition was limited to a vertical velocity of 15 feet per second for a touchdown weight of 10,600 pounds. The ground impact condition was based on a shock strut load derived from the dynamic analysis. The skid contact condition was taken as a 1.0-g load at the end of the skid, with two skids in contact with the ground and the load distributed over 8 inches of the skid.

The limit to ultimate factors considered were:

1. Ground Impact	
All Structure	1.33
2. Skid Contact	
Skids	1.00
All Other Structure	1.33
3. Water Impact	
All Structure	1.00

The aft heat shield and skids were analyzed for a temperature of 600 F, and the inner structure for a temperature of 200 F. These values are the maximum temperatures used for the Apollo analysis. The value of 600 F is conservative in that it is the maximum temperature expected at the ablator-heat shield interface.

Aft Heat Shield Substructure

For this concept, the hoop continuity and overall stiffness of the Apollo heat shield structure is retained; therefore, flight loading conditions up to and including the 20-g entry condition require no analytical consideration. With the heat shield deployed, all loads are reacted at the six-strut attachment points. To distribute their shock strut concentrated loads, a box section ring has been added to the structure above the inner face sheet at a 71-inch radius. The radial skid housings are designed to replace strength and stiffness of the heat shield material removed to accommodate the skids.

Extendable Skids

The 12 extendable skids are supported by 12 housings welded into the aft heat shield substructure. These housings are positioned radially with the inboard and outboard ends supported by load distribution rings. The outboard ring picks up the six shock struts, which react the load on the command module inner structure aft sidewall.

Command Module Inner Structure

When retracted, the aft heat shield is bolted to the inner structure at the aft bulkhead ring with 24 explosive bolts. These bolts can easily carry the tension loads that can occur at this interface. The lateral shear is taken by 59 studs in the aft bulkhead ring. When the aft heat shield is deployed, all vertical load on it is transmitted to the inner structure by the shock struts. The forward end of each shock strut is attached to a fitting which introduces the load to the inner structure aft sidewall. This fitting is bolted to the girth ring and to the aft bulkhead ring, and is bonded to the aft sidewall skin. The radial component of the shock strut load is carried in bending by the fitting and is reacted at the two rings. The vertical component is carried in shear in the aft sidewall skins, the load being introduced by the adhesive bond. The preliminary stress analysis has shown that the command module inner structure is compatible with the MISDAS installation.

Results

The radial-skid design concept as shown in Figure 13 can satisfy the structural requirements. The member sizes calculated in this analysis were used to obtain the system weights shown in the Mass Properties discussion for the radial skid concept. Preliminary calculations of heat shield deflection have shown that the command module inner structure will not be hit or damaged for the specified landing conditions. Table 5 shows the critical condition, stress, and margin of safety for each major component. The stress analysis is given in Appendix A of this report.

STABILITY ANALYSIS

The fact that the spacecraft can make stable landings under all conditions listed in the guidelines, constraints, and design criteria section was verified by the dynamic stability analysis. To perform this analysis, a stability program was derived from an existing Apollo/crew couch two-body program. The modified stability program considers the heat shield and the command module as two complete bodies. The program geometry considers the heat shield with extended skids and the struts connecting the two bodies. The program calculates and plots the spacecraft position about three axes as a function of time after ground contact. This program is described in Reference 10. The results of the stability analysis are discussed in the following paragraphs.

The program is based on assumptions of rigid ground plane, rigid crew compartment, deployed heat shield with plastic and elastic properties, and shock struts with load-stroke characteristics that can be referenced by a series of straight lines.

Program inputs include:

1. Center of gravity coordinates
2. Strut end coordinates
3. Weight and mass properties
4. Strut and heat shield load-stroke characteristics
5. Landing velocities V_V and V_H
6. Roll, pitch, and yaw
7. Swing angle and direction of swing
8. Ground slope and direction of slope

Program outputs include:

1. Heat shield roll, pitch, and yaw versus time
2. Heat shield displacement, velocities, and acceleration versus time
3. Strut stroke versus time (each strut)
4. Hull roll, pitch, and yaw relative to heat shield versus time
5. Hull displacement, velocities, and acceleration relative to heat shield versus time.

Angle Conventions

To define roll, pitch, and yaw, the vehicle is first rolled about its vertical axis, pitched about its y axis, then yawed about the z axis on the capsule. The roll angle is always measured as the counterclockwise angle from the horizontal velocity to the vertical plane containing the capsule z axis. The net pitch angle is measured as the upward angle from the horizontal plane to the capsule z axis (Figure 17).

The ground slope is defined by a maximum slope and a direction of upslope. The direction of upslope is measured in a counterclockwise angle (right-hand rule) from the horizontal velocity. Positive slope is upslope.

Horizontal and vertical velocity always form the basic reference plane.

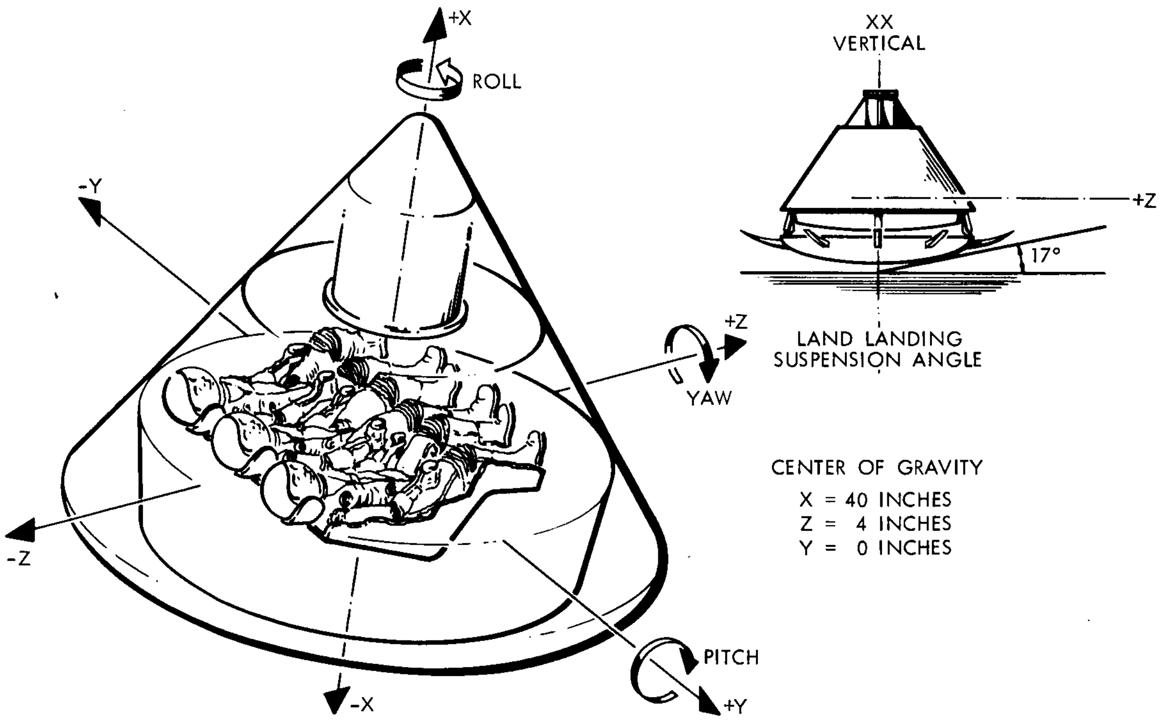


Figure 17. MISDAS/AES Land Landing Attitude, Deployable Heat Shield System

Skid System Vehicle Data

The weights, initial center of gravity location, and inertias of the two bodies used in the skid system analysis are noted below. These data are derived from AES mass properties modified to include the MISDAS installation.

Body	Weight (pounds)	Initial Center of Gravity (inches)			Inertias (slug ft^2)		
		x	y	z	x	y	z
Capsule	8210	58.7	-.1	8.7	3455	2540	2280
Heat shield	2780	8.0	0	0	1710	860	860

The actual vehicle has six vertical struts constraining the capsule to the heat shield plus the lateral support devices. Since the computer program is limited to eight struts, the vehicle analysis was based on four vertical struts and four lateral struts. This is considered a reasonable approximation.

The initial locations of the ends of the eight struts used were: (capsule initial system)

Strut No.		1	2	3	4	5	6	7	8
Heat shield	x	18.25	18.25	18.25	18.25	18.25	18.25	18.25	18.25
	y	0	-73.0	0	73.0	-73.0	73.0	-73.0	73.0
	z	73.0	0	-73.0	0	0	0	0	0
Capsule	x	46.0	46.0	46.0	46.0	18.25	18.25	18.25	18.25
	y	0	-61.0	0	61.0	0	0	0	0
	z	61.0	0	-61.0	0	73.0	73.0	-73.0	-73.0

Strut Load-Stroke Characteristics

The vertical struts used the force-stroke function given in Figure 18 for compression. To retain the heat shield to the capsule in other attitudes, dummy coulomb friction forces were added to the vertical struts in tension and to the lateral struts in both directions. The axial forces were 34,900 pounds for each of four struts and the lateral forces were 55,000 pounds per strut. Thus, the actual configuration uses six struts having 23,300 pounds loads, rather than four struts of 34,900 pounds load as shown in Figure 17. The stress analyses were based on the 23,300 pound actual strut load.

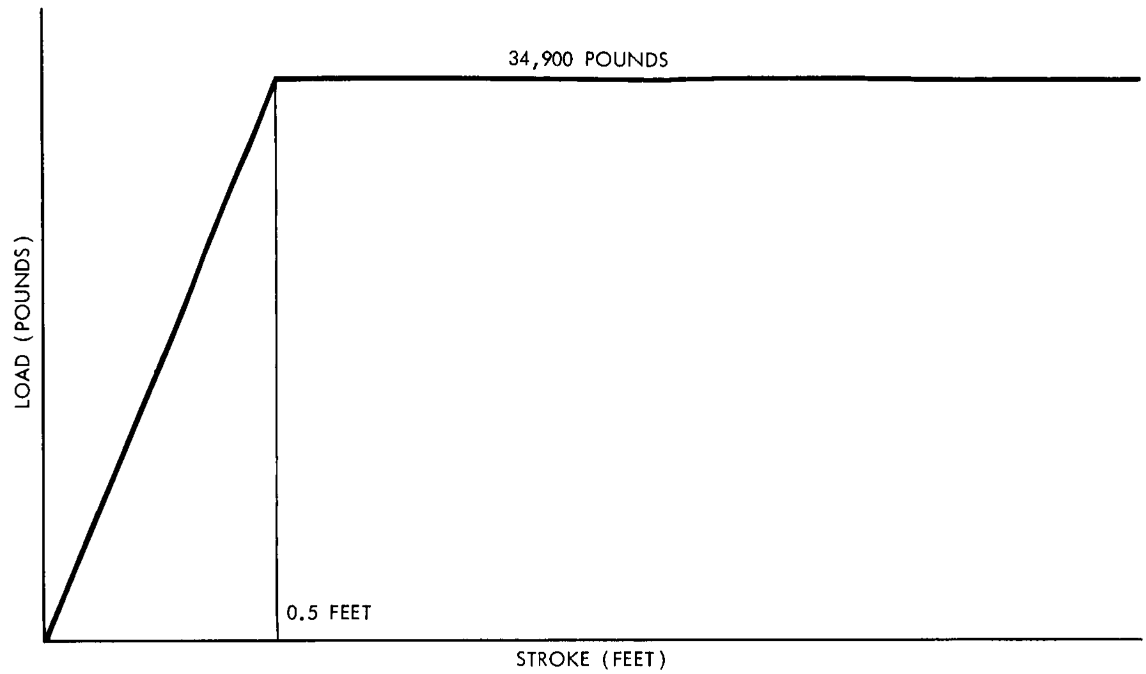


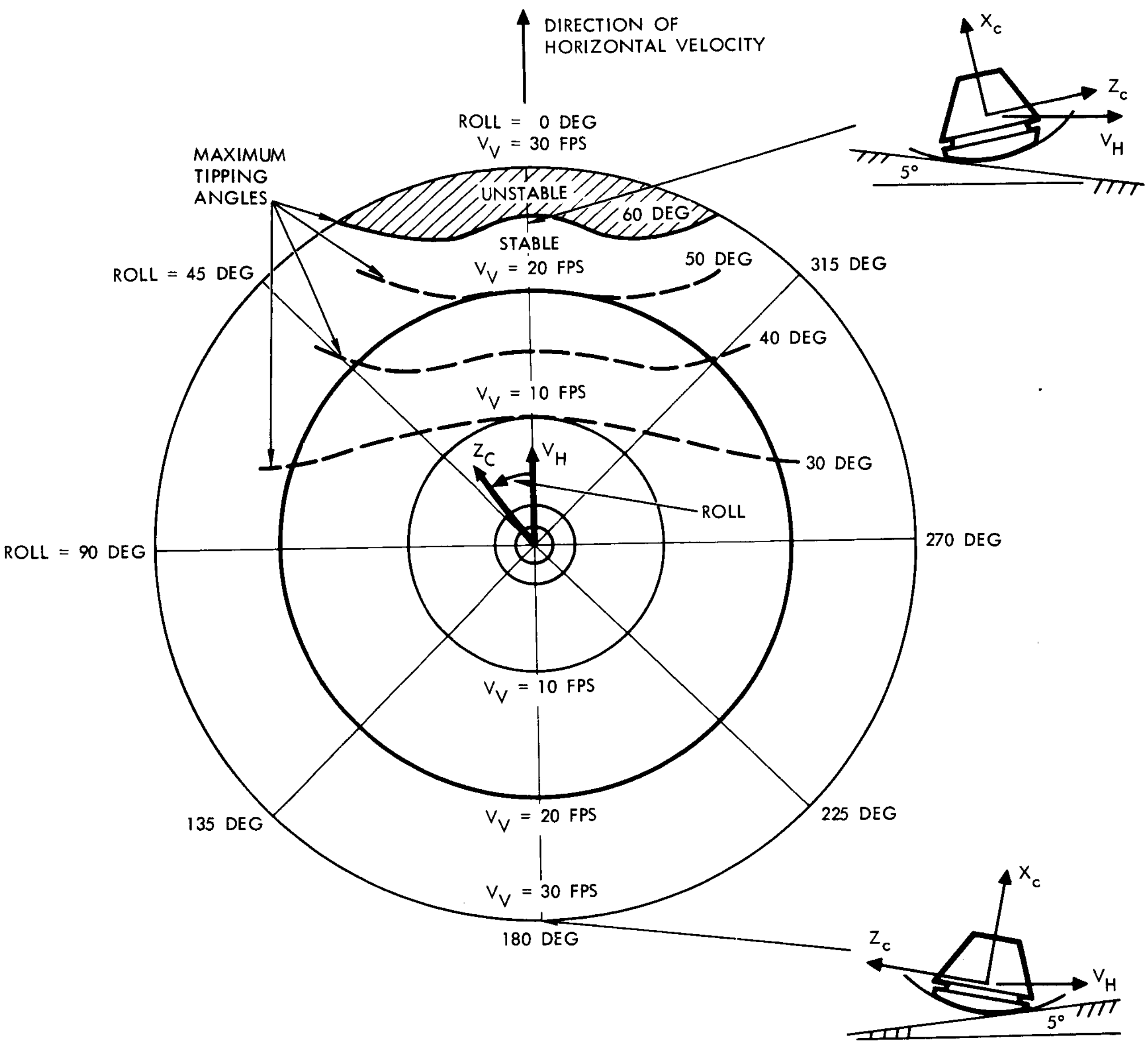
Figure 18. Load-Stroke Curve for the Skid System Vehicle With Vertical Struts

Crew Compartment Accelerations

The strut loads used on the deployed heat shield concept result in total accelerations on the crew compartment which are lower than maximum allowable Apollo values. For a landing with 80 feet per second horizontal velocity toward a 5-degree upslope, 15 feet per second vertical velocity, and angular attitude so that the center of the heat shield makes initial ground contact; the crew compartment will experience a 17.0-g acceleration normal to the ground plane and an onset rate of 34.0 g per foot. For a friction coefficient of 0.35, the total acceleration will be 18.0 g. The landing previously described will result in the most severe accelerations on the crew compartment. In this landing, a maximum normal velocity (22 feet per second) is achieved with all x-x axis struts stroking simultaneously. The strut properties of Figure 18 and a crew compartment weight of 8210 pounds have been used in the analysis. The load-stroke characteristics of the strut can be varied slightly without exceeding the crew tolerance limits or making the spacecraft unstable.

Stability of Skid System Vehicle

For landing conditions within the criteria previously stated, this vehicle showed good stability. Figure 19 shows the maximum tipping angles mapped as a function of vertical velocity and roll angle.



MAXIMUM TIPPING ANGLES MAPPED AS A FUNCTION OF VERTICAL VELOCITY FPS AND ROLL ANGLE, DEGREE, FROM VELOCITY PLANE (60 DEGREES IS UNSTABLE).

COEF. OF FRICTION = 0.35
HORIZONTAL VELOCITY = 30.0 FPS
SLOPE = 5 DEGREES DOWN
DIRECTION OF SLOPE = ALONG HORIZONTAL VELOCITY
SWING ANGLE = 12 DEGREES

Figure 19. Stability Limits for Radial Skids Vehicle

The figure shows that a maximum tipping angle of 40 degrees will be reached when landing at 15 feet per second vertical velocity, down a 5-degree slope, in a zero swing direction, and a swing angle of 12 degrees. This landing is the worst obtained for vertical velocities of 15 feet per second or less.

A stability summary is included for the deployed heat shield concept (Table 6). Landings upslope tend to stabilize the capsule but lead to greater strut stroking. The landing at V_H = 80 feet per second and V_V = 15 feet per second is a severe case since the struts previously described for this concept will be stroked so that the heat shield will be closed on one side after impact. Stiffer struts will be required for vertical velocities above 15 feet per second.

MASS PROPERTIES

To conform with the AES engineering weight data, the Apollo Block II weight data as given in Reference 10 were utilized as a base point to determine the weight penalty for adding a mechanical impact landing system. The weight penalty of the mechanical landing system is considered to be the weight of the landing gear system and the effect of all modification required on the aft heat shield structure and inner structure.

The spacecraft includes the retrorocket system with associated systems designed for AES on the Land Landing Study (LLS) to obtain a vertical descent velocity of 15 feet per second. To make the LLS design data compatible with the MISDAS installation, minor modifications were made and are reflected in the weight breakdown.

To establish a realistic volumetric comparison, only the volume penalty in the aft equipment bay was assessed. For purposes of this study, the volume penalty is considered to be the total usable volume displaced by the components, including the space provided for the movement of the struts and rocket motors.

Table 7 presents the weight breakdown of the deployable heat shield/ radially extendable skid concept, including the retrorocket system and its associated system necessary to obtain a desired impact velocity. The weight analyses are for the design shown in Figures 13, 14, and 15 and are based on detail structural analysis presented in Appendix A of this report, with allowance for items not shown in the figures and estimates for subsystems based on AES spacecraft data.

The landing gear system consisting of a skid assembly, outer support ring, shock strut assembly, and hydraulic and pneumatic system, is estimated to weigh 1030 pounds. This amounts to 9.72 percent of the design landing weight.

Table 6. Radial Skids System Stability Summary

Job No.	Horizontal Velocity	Vertical Velocity	Roll	Pitch	Yaw	Slope	Direct Slope	Friction	Stability	Maximum Tipping Angle	Notes on Struts
51	30	15	0	12	0	-5	0	0.35	All stable	37	Strut stroking acceptable
51	30	15	22.5	12	0	-5	0	0.35		37	
51	30	15	45	12	0	-5	0	0.35		32.7	
51	30	15	67.5	12	0	-5	0	0.35		25.2	
51	30	15	90.0	12	0	-5	0	0.35		2 .5	
53	30	15	0	12	0	-5	0	0.35		37	
53	30	15	22.5	12	0	-5	22.5	0.35		36.5	
53	30	15	45	12	0	-5	45	0.35		31.7	
53	30	15	67.5	12	0	-5	67.5	0.35		24.5	
53	30	15	90.0	12	0	-5	90.0	0.35		22.5	
56	30	20	0	12	0	-5	0	0.35		50	Strut stroking high (Marginal Case)
56	30	20	22.5	12	0	-5	0	0.35		48.3	
56	30	20	45	12	0	-5	0	0.35		39.1	
56	30	20	67	12	0	-5	0	0.35		31.3	
56	30	20	90.0	12	0	-5	0	0.35		22.9	

Table 6. Radial Skids System Stability Summary (Cont)

Job No.	Horizontal Velocity	Velocity Velocity	Roll	Pitch	Yaw	Slope	Direct Slope	Friction	Stability	Maximum Tipping Angle	Notes on Struts
56	30	25	0	12	0	-5	0	0.35	All stable	57	(Marginal Case) Strut stroking high
56	30	25	22.5	12	0	-5	0	0.35		58.5	
56	30	25	45	12	0	-5	0	0.35		42.0	
56	30	25	67.5	12	0	-5	0	0.35		32.0	
66	80	15	0	-12	0	5	0	0.35		17	
66	80	20	0	-12	0	5	0	0.35		17	
66	80	30	0	-12	0	5	0	0.35		17	

Table 7. Weight of Radial Skid Concept

Item	Weight (lb)		
	Apollo Block II (Sept. 65)	AES Addendum	Weight Change
Art Heat Shield Structure	(763. 3)	(470. 3)	(-293.)
Honeycomb panel*	(559. 6)	(305. 0)	(-254. 6)
Core	202. 9	157. 0	- 45. 9
Face sheets	305. 6	103. 0	-202. 6
Braze	51. 1	45. 0	- 6. 1
Frames and rings			
Ring outer rim	55. 1	55. 1	0. 0
Body to heat shield attach**	55. 9	15. 0	- 40. 9
Fitting and attach	33. 0	33. 0	0. 0
Closeouts***	7. 1	10. 0	2. 9
Toroidal assembly	(52. 6)	(52. 2)	- 0. 4
Corrugation	16. 6	15. 0	- 1. 6
Skin	17. 7	16. 0	- 1. 7
Splice and attach	18. 3	21. 2	2. 7
Landing Gear Assembly		(1030. 0)	(1030. 0)
Skid Assembly		(595. 0)	595. 0
Skid housing (12)		277. 0	
Skids (12)		260. 0	
Inner ring		17. 0	
Skid extension device		41. 0	
Ring, outer support		290. 0	290. 0

*Honeycomb panel — reduced core density and face sheet thickness to conform to decrease in landing load.

**Body to heat shield attach — body to heat shield attach point reduced from 59 to 12. In addition, an explosive release mechanism is provided for heat shield deployment.

***Closeouts — edge member provided at skid housing and toroidal assembly interface.

Table 7. Weight of Radial Skid Concept (Cont)

Item	Weight (lb)		
	Apollo Block II (Sept. 65)	AES Addendum	Weight Change
Shock Strut Assembly		(113.0)	113.0
Struts (6)		60.0	
Lateral supports		24.0	
Attach fittings - sidewall		25.0	
Hardware		4.0	
Hydraulic and Pneumatic System		(32.0)	32.0
Hydraulic accumulator		6.0	
Motor valve		2.0	
Valves		0.5	
Dampening orifices		1.0	
Plumbing		7.0	
Electrical provision		0.5	
Support and attaching parts		1.5	
Hydraulic fluid		13.0	
Gas (helium)		0.5	
Subtotal	763.3	1500.3	737.0
Total Mechanical Landing System Penalty (Usable volume displaced - ft^3)			737.0 (3.5)

The weight penalty of the mechanical landing system is the net weight penalty of the landing gear system weight combined with the weight change of the aft heat shield structure. This net weight penalty amounts to 737 pounds (6.95 percent). The heat shield weight change results from the reduction in water impact velocity to 15 fps. The heat shield weights for AES and MISDAS are based on the stress analyses.

MANUFACTURING CONSIDERATIONS

From a manufacturing standpoint, the aft heat shield incorporating radial skid housings can be considered as a new design. However, design effort has been directed toward the utilization of the Apollo tooling and fabrication techniques as much as possible. The changes on the crew compartment are comparatively minor. In general, these include installation of additional items, such as the actuators and support bracketry.

Manufacturing considerations placed few constraints on the aft heat shield basic engineering design. Minor changes were made in some areas to improve the producibility aspects. The materials contemplated for these units are the same as currently used on Apollo, PH 14-8 Mo and PH 17-4.

Crew Compartment

To incorporate MISDAS in the AES involves some minor changes in the crew compartment, requiring installation of support brackets, actuators, lateral braces, new attach points for joining to the aft shield, wiring and attendant systems for firing attach bolts and skid extender propellant, and other miscellaneous hardware (Figure 20). The attachment of this hardware is to be accomplished on a completed unit with very little tooling involved.

Aft Heat Shield

The aft heat shield structure is fabricated as a six-segmented center heat shield of brazed honeycomb to which are welded 12 skid housings and 12 truncated pie-shaped outer segments of brazed honeycomb. This subassembly is finished to the same diameter as the Apollo heat shield. Attached to the periphery is a corrugated toroidal structure much the same as the one currently used. Additionally, an outer support ring is riveted to the inner surface of the shield to which the actuators are joined. Skids are inserted within the skid housings and the whole unit has ablation material added in the usual manner, except that the ablation material added to the skid will be separated with a "no-bond" separator, permitting extension of the skid.

Center Heat Shield Section

This portion of the heat shield, as already mentioned, consists of six segments. Each segment is a honeycomb sandwich with stretch-formed face

sheets, chem-mill sculptured to provide welding lands and then braze-heat-treated with the core. The inner support ring segment is machined as a ring in the heat-treated condition and then segmented. The brazed segment subassembly will be trimmed to fit, decored, and excess braze alloy removed prior to butt-welding to the inner support ring segment. Three of the segments will be handled in a similar manner. These two half circles will then be joined to complete this subassembly. In general, butt-fusion welding of both surfaces of sandwich panels will be done concurrently.

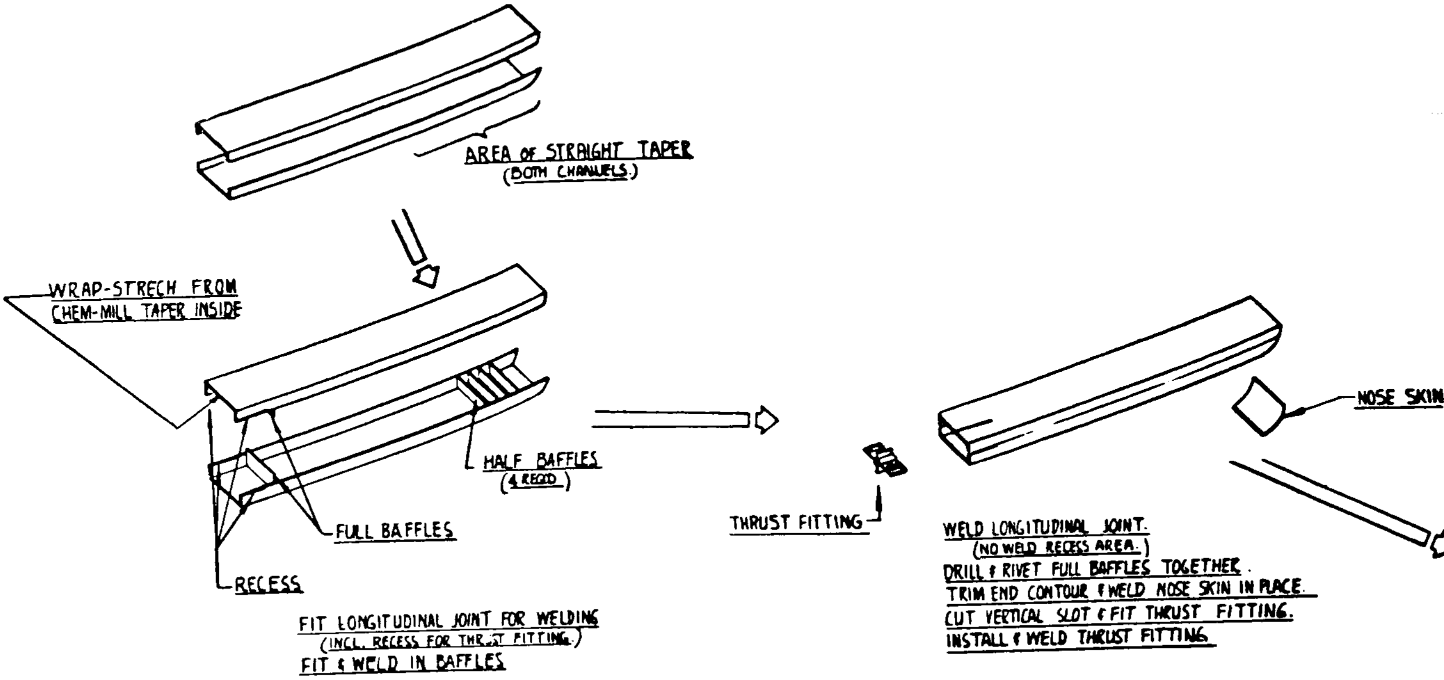
This particular manufacturing approach was used for the center heat shield as it was believed to be more predictable based on past experiences, particularly with reference to the B-70. The possibility of butt-welding the edge member, as a full ring, to a one-piece center portion was considered, but it was believed a full ring weld, even though done in a staggered fashion, would introduce excessive stresses and distortion. Another method that should be studied further involves a completely brazed one-piece assembly rather than a segmented assembly. The edge member would be machined as a full ring, the skins stretch-formed, and the whole unit braze-heat-treated as a complete assembly. Experience on the B-70 has indicated that brazed faying surfaces were troublesome, lacking consistency and reliability. Therefore, development effort would be necessary to verify a consistent process. This latter method would reduce weight as well as cost, when a technique is developed.

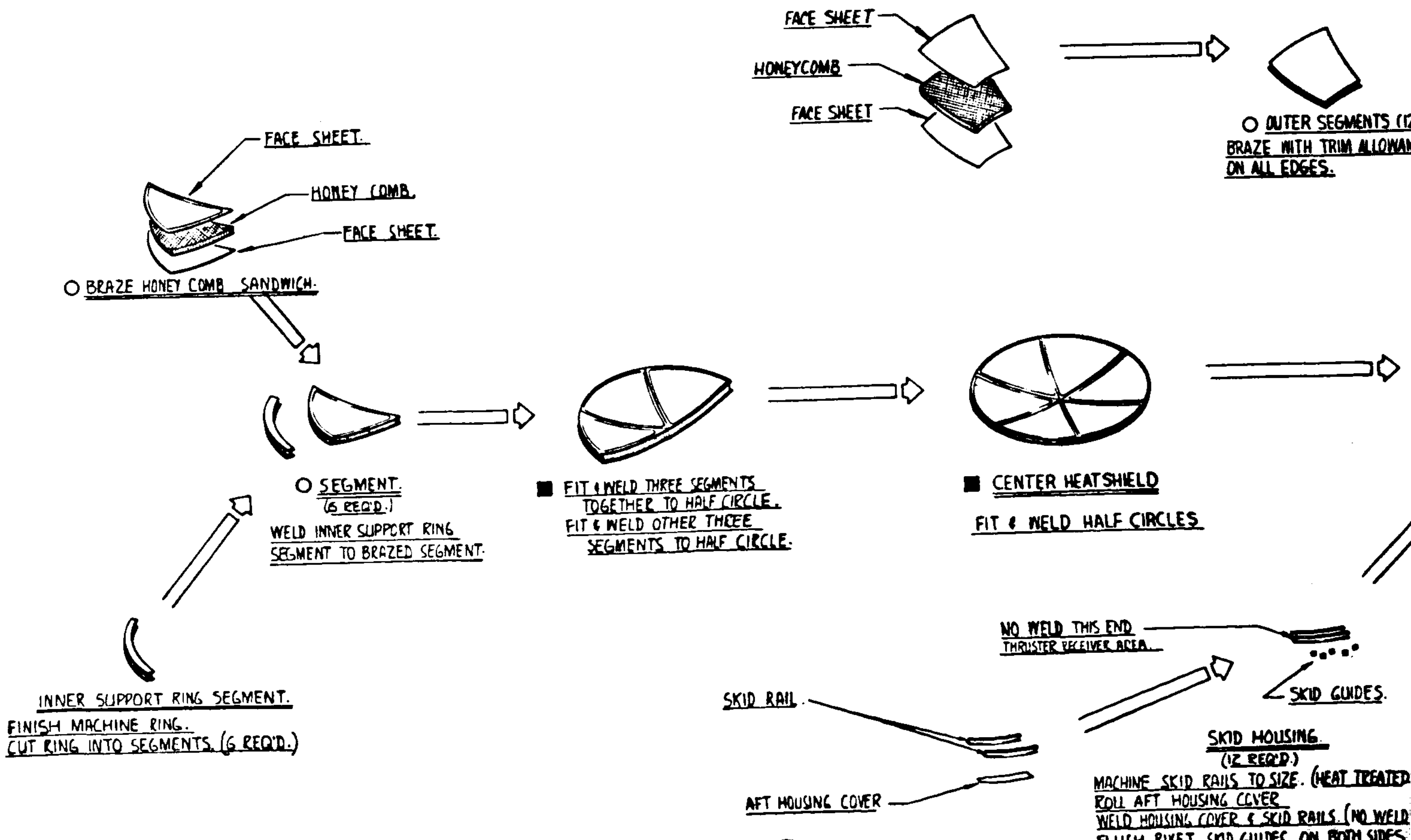
Outer Segments

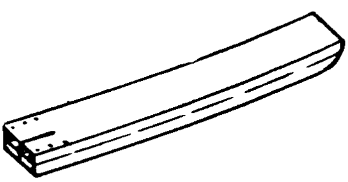
The 12 outer segments of honeycomb will be made in a manner similar to the previously described center heat shield. The face sheets will be stretch-formed and chem-mill sculptured and then brazed to the core in the usual manner. No edge members are necessary; however, excess trim will be allowed for fitup at the next assembly.

Skid Housing Assembly

This assembly is a machined and welded assembly consisting of two machined skid rails, an aft-housing cover and a series of skid guides which are riveted to the inside of the rails to steady the skid as it extends. The skid rails will be machined completely out of heat-treated contoured bars. The connecting sheet is rolled, chem-mill sculptured to provide welding lands, and then notched to permit insertion and welding of the thruster receiver at a later operation. The two side rails (right and left) will be butt-welded to the connecting sheet, except in the area of the thruster receiver attachment. The skid guides (of either Teflon or aluminum) will be installed on the inside surface of the sides and flush riveted. Material is left on the skid bearing surfaces so that a light finishing cut can be taken after all welding has been completed, and will be done on the next assembly.

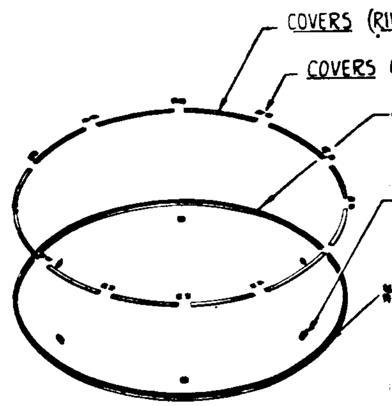

AREA OF STRAIGHT TAPER
(BOTH CHANNELS.)
WRAP-STRECH FROM
CHEM-MILL TAPER INSIDE
HALF BAFFLES
(4 REQD.)
FULL BAFFLES
RECESS
FIT LONGITUDINAL JOINT FOR WELDING
(INCL. RECESS FOR THRUST FITTING.)
FIT & WELD IN BAFFLES
THRUST FITTING
NOSE SKIN
WELD LONGITUDINAL JOINT.
(NO WELD RECESS AREA.)
DRILL & RIVET FULL BAFFLES TOGETHER.
TRIM END CONTOUR & WELD NOSE SKIN IN PLACE.
CUT VERTICAL SLOT & FIT THRUST FITTING.
INSTALL & WELD THRUST FITTING


FACE SHEET
HONEYCOMB
FACE SHEET
O OUTER SEGMENTS (1
BRAZE WITH TRIM ALLOWAN
ON ALL EDGES.
FACE SHEET.
HONEY COMB.
FACE SHEET.
O BRAZE HONEY COMB SANDWICH.
O SEGMENT.
(6 REQ'D.)
WELD INNER SUPPORT RING
SEGMENT TO BRAZED SEGMENT.
■ FIT & WELD THREE SEGMENTS
TOGETHER TO HALF CIRCLE.
FIT & WELD OTHER THREE
SEGMENTS TO HALF CIRCLE.
■ CENTER HEATSHIELD
FIT & WELD HALF CIRCLES
INNER SUPPORT RING SEGMENT.
FINISH MACHINE RING.
CUT RING INTO SEGMENTS. (6 REQ'D.)
NO WELD THIS END
THRUSTER RECEIVER AREA.
SKID RAIL
SKID GUIDES.
AFT HOUSING COVER
SKID HOUSING.
(12 REQ'D.)
MACHINE SKID RAILS TO SIZE. (HEAT TREATED
ROLL AFT HOUSING COVER
WELD HOUSING COVER & SKID RAILS. (NO WELD
FLUSH RIVET SKID GUIDES ON BOTH SIDES.



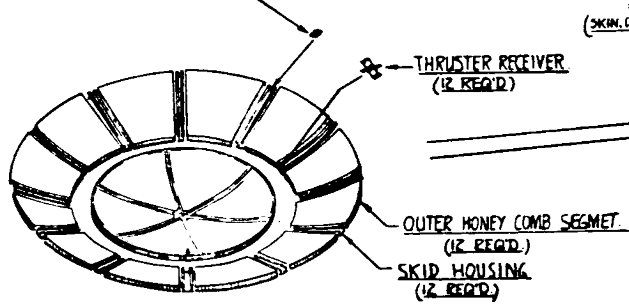
O SKID ASSEMBLY (12) REQ'D.

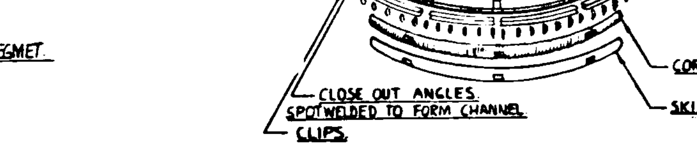
HEAT TREAT & STRAIGHTEN
REAM THRUST FITTING
DRILL & TAP HOLES FOR SKID STOP
MACHINE SKID IN AREA OF RAILS



O OUTER SUPPORT RING.
MACHINE RING (HEAT TREATED)
LOCATE & RIVET ACTUATOR ATTACH BRACKETS.
DRILL HOLES THRU BOTH FLANGES FOR ATTACHING COVERS
(COVERS ATTACHED AFTER INSTALLATION.)

REQ'D.)
CES





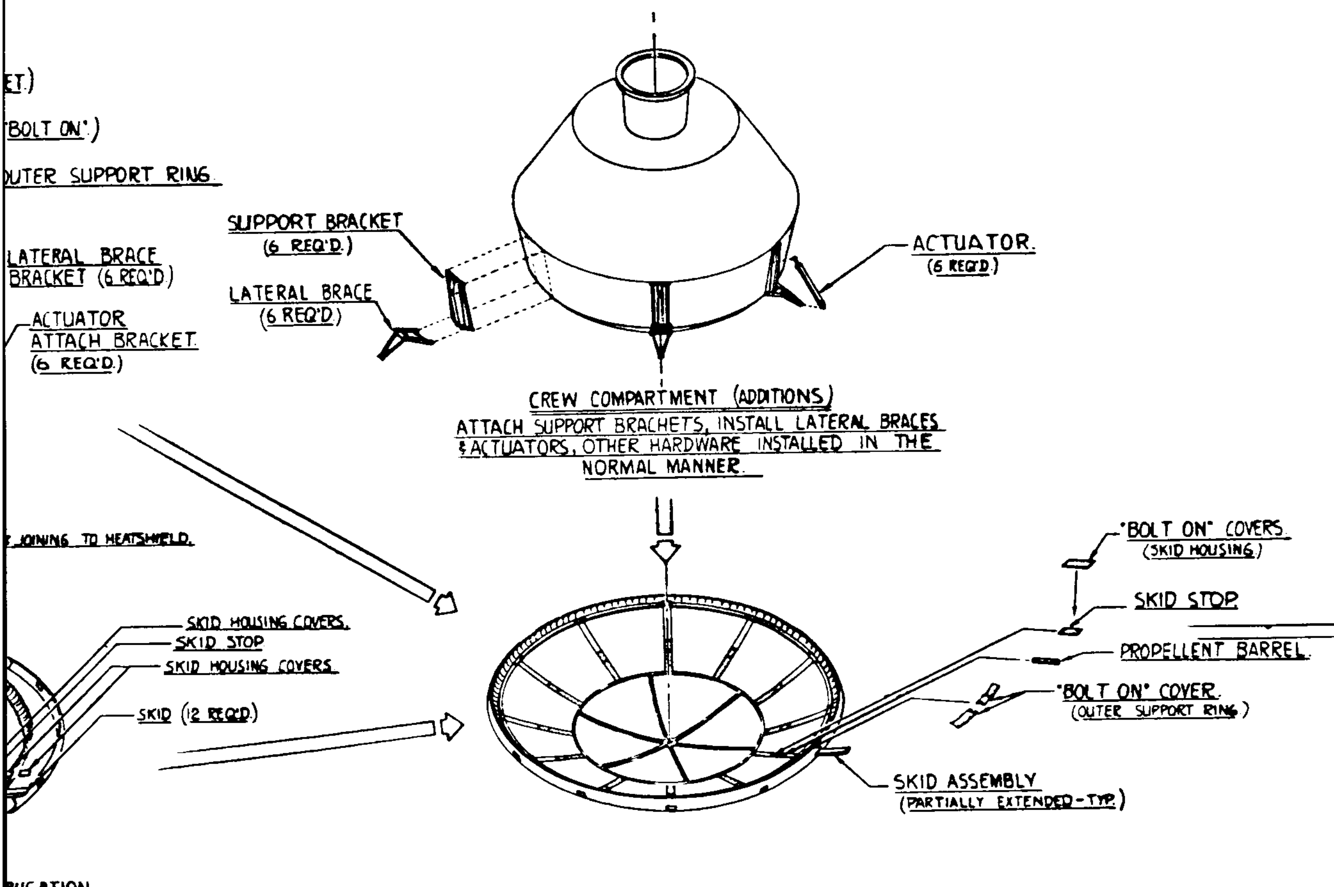
● AFT HEATSHIELD SUB-ASSEMBLY

INSTALL SKID HOUSINGS & WELD TO CENTER HEATSHIELD.
FIT & WELD OUTER SEGMENTS TO CENTER HEATSHIELD & THEN TO SKID HOUSING.
WELD SKID HOUSING BLOCKS TO SKID HOUSING.
FINISH MACHINE INNER RAILS OF SKID HOUSING & SKID GUIDES.
LOCATE & WELD THRUSTER RECEIVER IN END OF SKID HOUSING.
(USE APPLY TOOLING.)
MACHINE SKID HOUSING BLOCKS TO MATE WITH CREW COMPARTMENT.
MACHINE OUTER PERIPHERY FOR INSTALLATION OF CORRUGATED STRUCTURE.

■ HEATSHIELD ASSEMBLY

INSTALL OUTER RING, BLIND RIVET TO HONEY COMB SECTIO
INSTALL LATERAL BRACE BRACKETS, LOCATING FROM ACTU
CHECK FIT OF SKID IN HOUSING. REMOVE & IDENTIFY
INSTALL SUPPORT RING COVERS WHICH RIVET TO RING. (
RIVET SKID HOUSING COVERS IN PLACE. (INBOARD COVER
RECHECK FIT OF SKID & ESTABLISH SKID STOP POSITION
INSTALL CORRUGATED STRUCTURE.
REINSTALL SKIDS & TEMPORARILY ATTACH IN THEIR CLOS
SEND TO VENDOR FOR INSTALLATION OF ABLATIVE MATE

N AREA OF THRUSTER RECEIVER.)
OF HOUSING.

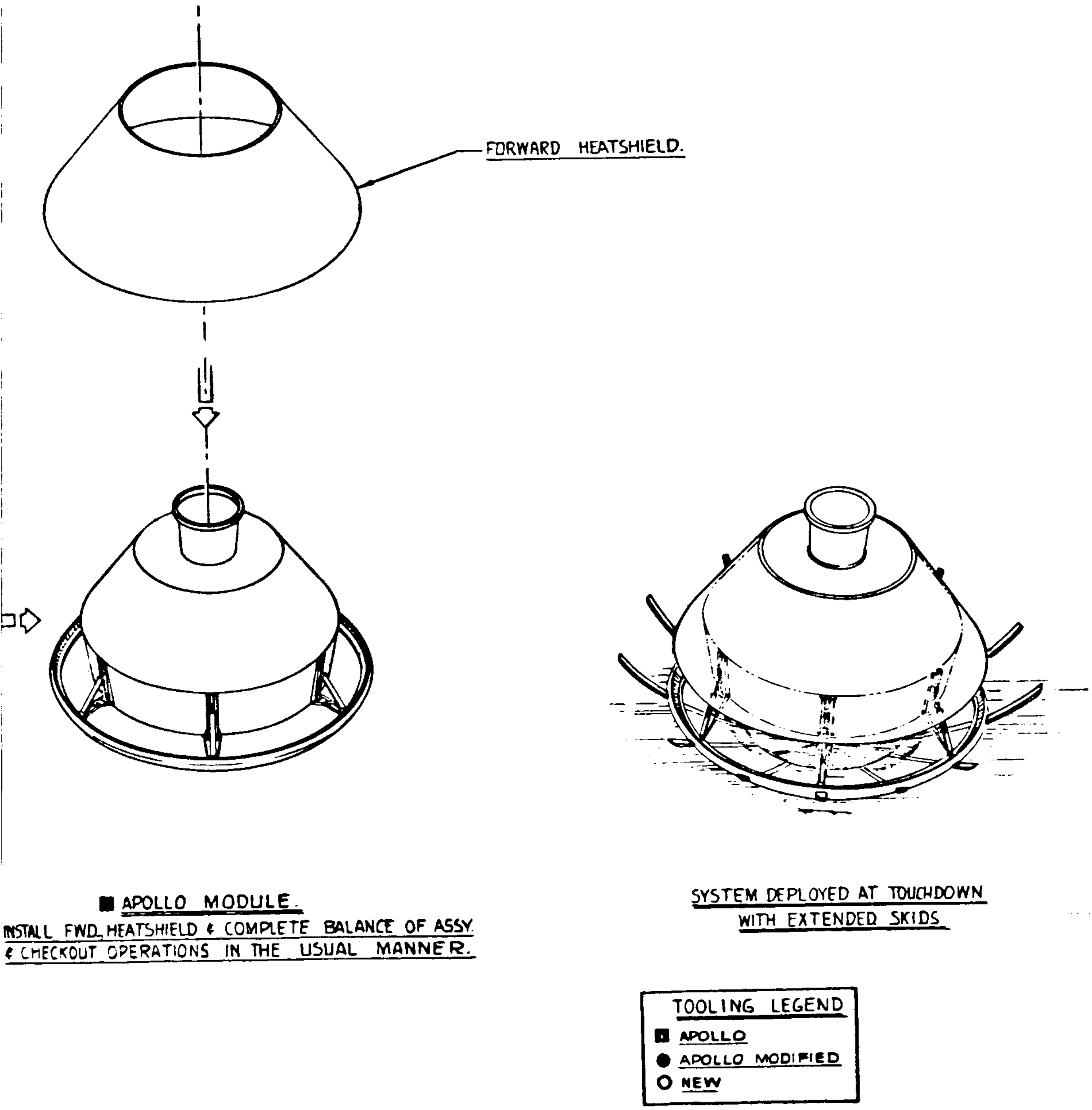


NS & RIVET TO HOUSINGS.
ATOR ATTACHMENT LUGS.
LT ON' COVERS INSTALL LATER.)
BOLTS ON.)
D POSITION
IAL.

■ FINAL ASSEMBLY - HEAT SHIELD.

VENDOR INSTALL ABLATIVE MATERIAL, PROTECTIVELY PACK & RETURN TO S&ID.
REMOVE TEMPORARY SKID ATTACHMENT, ADD SKID STOP & EXTEND SKID PARTIALLY.
INSTALL PROPELLENT BARREL IN THRUST RECEIVER & RETRACT SKID.
INSTALL "BOLT ON" SKID HOUSING COVERS.
INSTALL CREW COMPARTMENT.
ATTACH LATERAL BRACE & ACTUATOR TO OUTER RING & INSTALL "BOLT ON" COVERS.
INSTALL EXPLOSIVE TYPE ATTACHMENT FOR JOINING CREW COMPARTMENT
& AFT HEATSHIELD ASSEMBLY.

Fi



ure 20. Manufacturing Breakdown, Deployable Heat Shield Extended Skids, MISDAS, Study

Aft Heat Shield Subassembly

During the aft heat shield subassembly operations, the 12 skid housings and outer segments are butt-weld joined to the center heat shield as well as to each other. Additionally, the 12 thruster receivers and 24 skid housing blocks are welded in place. The sequence of operations is important and will probably be as outlined here. The skid housings will be installed first and butt-welded to the inner support ring at the surfaces provided. The outer end of the housing will be jig-located. After fitting and trimming, the outer segments will be welded to the center heat shield and then to the skid housing. A welding sequence for the radial welds will be developed on the first few units.

The 24 skid housing blocks will be welded to the upper rail surfaces. A light finishing cut will then be taken on the skid bearing surfaces of the skid housing. The thruster receiver will be installed next, its location determined by apply-type tooling, indexing from the skid bearing surfaces. This will be a manual-type weld operation.

Machining of the skid housing blocks to mate with the crew compartment is one of the last operations performed. The hole pattern will be match-drilled, requiring a comparatively simple master. The last operation in this fixture is to machine and decore the outer periphery of the honeycomb outer segments and skid housing for installation of the corrugated structure. The unit is now ready for final assembly operations which include installation of the skids, outer support ring, as well as the corrugated structure.

Skids

Manufacturing of the skids involves forming the channels wrap-stretch formed and chem-mill tapered on the inside surface in the required area. The longitudinal joint, including the recessed area for acceptance of the thrust fitting, will be machined for welding. The two full baffles are located and welded, one in each section. Four half baffles are located in the lower section and welded. The longitudinal weld is made, after which the two full baffles are riveted together. The outboard end will be cut to contour and the nose skin welded into place. A vertical slot is cut in the inboard end and the thrust fitting is mated and welded to the skid. The completed weld assembly will then be heat-treated, after which the thrust fitting is reamed and holes will be drilled and tapped for the skid stop. Those areas that ride in the skid housing rails will be machined to final dimensions and curvature to ensure a sliding fit.

Outer Support Ring

The load-carrying outer support ring will be machined in one piece (except for the covers) out of heat-treated material. This method was selected over fabricating the unit of formed sheet material wrap-stretch/ wipe-formed on a Cyril Bath stretch former. Tooling and fabrication costs will be high for the stretching operation, trimming after stretching, weld-joining the segments together, and flush-riveting the lower cover plates. In addition, the fit of the formed sheet metal part on the heat shield may require additional hand work before riveting to the structure. The machined part should not present these problems. After machining, the actuator attach brackets will be located and riveted within the ring. The covers will be made, holes drilled for their attachment, and the parts identified for relocation at final assembly. Since the holes in the flange for attaching the ring to the structure are not easily accessible, they will be drilled at the time the cover holes are drilled by drilling straight through from the upper flange.

Final Structural Assembly

The first operation in the final structural assembly is to blind-rivet the outer support ring to the aft heat shield subassembly. Rivet holes will be drilled from holes previously drilled in the ring flanges. The lateral brace bracket locates from the actuator attach bracket and rivets in conjunction with the attachment procedure previously mentioned. The riveted ring covers will then be installed, leaving the bolted covers for later installation. At this point, the skids will be inserted to verify their fit, and rework where necessary. The skids will be removed and the skid housing covers riveted (inboard covers bolt on) in place. Next, the skids will be reinstalled, the skid stop bolted in place, and the correct stop position established. Temporarily, the skids will be attached in their closed position for shipment to the contractor for installation of the ablative material. The toroidal corrugated structure will be installed as the last operation in the same fixture and in the manner currently used. The unit will then be ready for shipment to the ablative installation contractor.

Ablative Installation

It is anticipated that the ablator installation will follow the procedures used for Apollo. The contractor will install ablative material in the usual manner except for the end of the skids. To ensure positive movement at extension, the ablative material will be added to the skid as a plug with a Teflon or other "no-bond" separator between it and the balance of the heat shield ablator. The total heat shield will then be ground to the correct contour and returned to S&ID.

Final Buildup

In going through the final buildup, only those items peculiar to the AES installation will be considered. The order in which they are mentioned is not necessarily critical, unless they are sequencing operations. The installations and operations required will be interspersed with those normally associated with a conventional Apollo buildup. For instance, installation of those items containing explosives will be installed as late in the process as possible and by personnel experienced and trained in their handling.

Before installation of the crew compartment, the temporary skid attachment will be removed and the skid partially extended to permit installation of the propellant barrel in the thruster receiver, which has already been welded to the skid housing. The skid will be retracted, verifying clearances, etc., and its position will be fixed.

The bolt-on skid housing covers will then be installed. During installation of the crew compartment, the lateral arrestor brace and the actuator will be joined to the outer support ring, after which bolt-on covers will be installed, closing out the support ring box section. Explosive-type attachments will be installed, joining the crew compartment and aft heat shield. Electrical circuitry for firing these breakaway units will be checked out prior to final hookup. The balance of operations and checkout will proceed as normal Apollo manufacturing operations.

CONCLUSIONS AND RECOMMENDATIONS

The preliminary technical studies of the application of MISDAS indicate the feasibility of installing either concept in the AES spacecraft. The radial skid/deployed heat shield design (Figure 13) and the six-segment hinged heat shield concept (Figure 4) can both provide stable landing and satisfactory impact attenuation within the range of horizontal and vertical velocities, spacecraft-ground attitudes, and ground conditions specified in the Guidelines Constraints and Design Criteria section.

RESULTS OF STUDY

To conform with the AES engineering weight data, the Apollo Block II weight data was utilized as a base point to determine the weight penalty for adding a mechanical impact landing system. The weight penalty of the mechanical landing system is considered to be the weight of the landing gear system and the effect of all modification required on the aft heat shield structure and inner structure.

Table 8 presents a summary weight and balance comparison of the basic and modified Apollo command module. For purposes of comparison, the command module is shown in the basic form of Apollo Block II, Apollo Block II + segmented heat shield modification, and Apollo Block II + deployable heat shield/radially extendible skid modification in the launch, prior to impact, and at impact flight condition. These weights include the AES retro-rocket system and its related subsystems, which are not part of the MISDAS system.

The data in Table 8 indicate that the weight penalties of the mechanical landing system for the six-segmented heat shield concept and the deployable heat shield/radially extendible skid concept are, 5.25 and 6.95 percent, respectively, of the design landing gross weight. This compares with the design goal of 3.5 percent established by NASA.

Within the landing criteria considered in this program, both vehicle concepts appear capable of stable land landings. Although all possible landing cases were not investigated, the most adverse conditions were identified. Several statements can be made regarding stability trends:

1. Vehicle stability will decrease sharply with an increase in the effective friction coefficient of the vehicle with the ground.

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2. Vehicle stability decreases rapidly with an increase in normal velocity to the ground.

3. For friction independent of sliding velocity, horizontal velocity has little effect on stability except for its contribution to normal velocity.

4. The effects of ground slope, slope direction, parachute swing angle, parachute direction of swing, and roll angle on stability are not easily identified. Therefore, most of the stability study was done for different combinations of these angles. The most unstable condition was landing with horizontal velocity in the direction of downslope and a maximum impact angle of 17 degrees (12-degree parachute angle), zero-degree direction of swing, roll angle of zero degrees).

5. A horizontal velocity of 30 feet per second has been used to determine the stability envelope. This velocity is sufficiently large to allow the vehicle to slide after initial impact without appreciably changing its normal velocity when landing on up or down slopes. Larger horizontal velocities have been found to give a resultant decrease in normal velocity, with stabilizing effects on the vehicle landing up or downslope.

The design investigations of integration of retrorockets and the mechanical impact attenuation systems into the Block II Apollo command module indicate that such an integration is technically and physically feasible for both the segmented heat shield concept and the deployable heat shield/radial skid concept. It must be recognized that the actual structural modifications and equipment rearrangement of the high-density packaging in the aft equipment bay necessary to accommodate the retrorocket and mechanical impact attenuation systems are significant changes, although vehicle shape and mold lines are not affected. The requirements and conceptual design of the shock struts were reviewed by the Loud Company, Menasco Manufacturing Company, and the Cleveland Pneumatic Tool Company, and found to be feasible. Appendix B presents a letter from the Cleveland Pneumatic Tool Company commenting on the design. Only normal engineering development is required for these members.

SUGGESTED FOLLOW-ON PROGRAMS

A final definition of the MISDAS installation in AES will require a detail design, development, fabrication, and test program. The major steps and preliminary schedule in such a program are outlined in the following section and in Figure 21. It is recommended that a follow-on effort be initiated, especially in the following areas.

Table 8. Summary Weight and Balance Comparison

Vehicle Mode	Apollo Block II (AES Addendum)				Segmented Heat Shield				Radially Extended Skids			
	Weight (lb)	C.G. (in.)			Weight (lb)	C.G. (in.)			Weight (lb)	C.G. (in.)		
		X	Y	Z		X	Y	Z		X	Y	Z
Command Module												
Launch	10,653	1042.1	0.0	7.2	11,438	1040.5	0.0	6.6	11,617	1039.3	0.0	6.3
*Prior to Impact (Gear-up)					10,221	1036.1	0.2	5.7	10,400	1034.2	0.2	6.3
*Impact (Gear-down)	9,436	1037.5	0.2	6.3	10,157*	1035.3	0.2	5.7	10,336**	1034.4	0.2	5.4

Note: Centers of gravity are in the NASA reference system, except that the longitudinal axis has an origin 1000 inches below the tangency point of the command module aft heat shield structure mold line.

*Low altitude abort condition

**Less retrorocket propellant

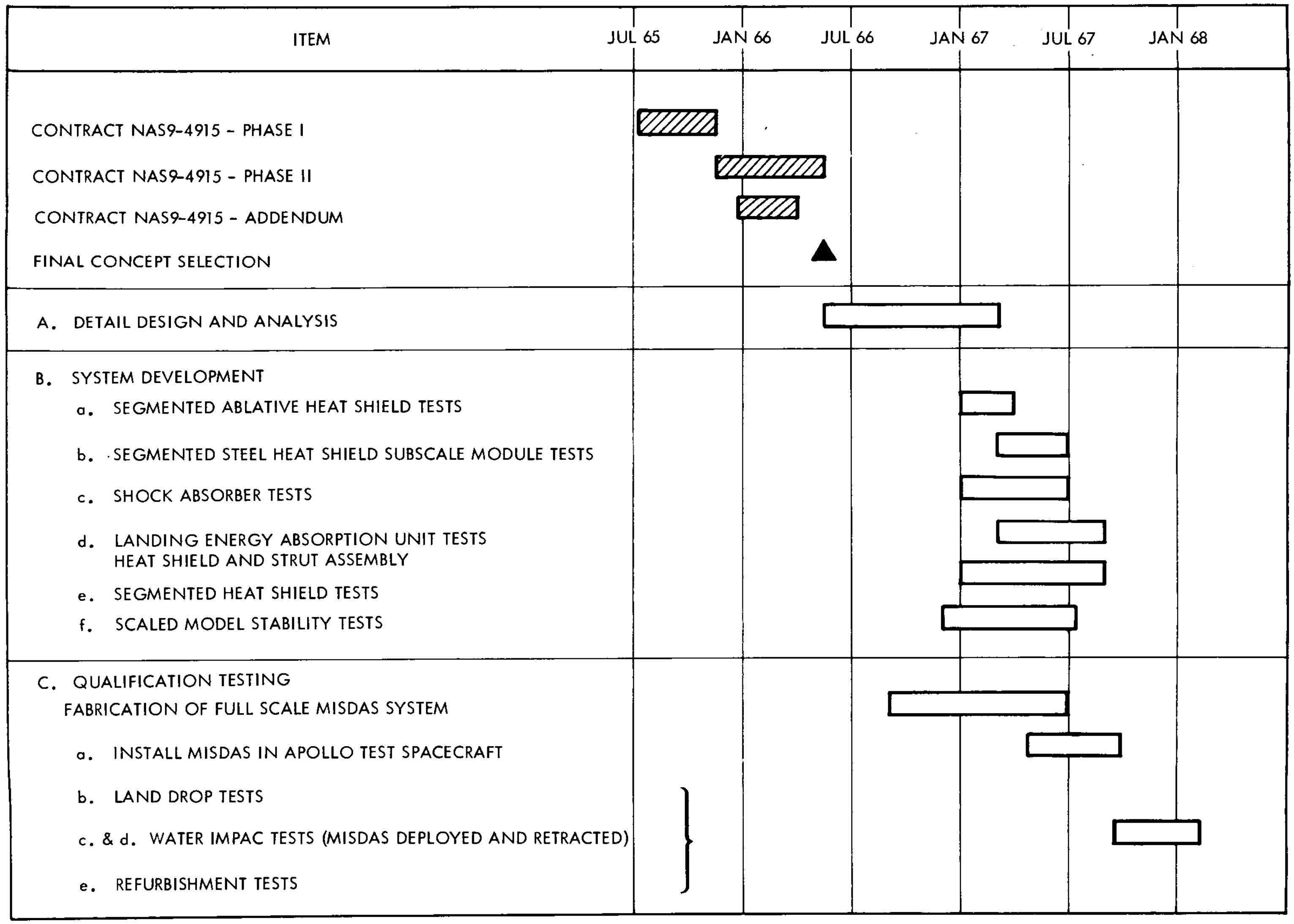


Figure 21. Suggested Design, Development, and Qualification Program, Preliminary Schedule

Development of Segmented Heat Shields

This effort should involve (1) investigation of problems related to space exposure, entry, deployment, and landing of a craft with a heat shield segmented to permit deployment and use of portions of it as landing and impact absorption element, (2) study of heat shield splices, ablative non-adhesive edge members, hinge and separation lines, and deployment devices, and (3) fabrication and testing of segmented ablative heat shield specimen under representative entry conditions to evaluate edge erosion, ablation, and sealing.

Stability of Legged Vehicles

This effort should involve the expansion of computer programs developed under Contract NAS9-4915 to cover more realistic situations, ground conditions, and vehicle attitude than those assumed during the contract.

Scale Model Tests of Stability and Impact Attenuation

Verification should be made of stability and attenuation values obtained theoretically through model testing, to raise confidence level and to determine the influence ground slope, terrain discontinuities, ground coefficient of friction, etc.

Installation of MISDAS on Apollo Boiler Plate

Verification should be made of volume and weight requirements of actual hardware; structural effects of landing loads on inner structure and support bracketry; overall acceleration levels in the vehicle, specially life supported systems; verification by testing of water landing capability of a vehicle equipped with ground landing attenuation systems.

Shell Dynamics of Land Impact

Analytical and test verification should be made of the interaction of a spherical shell structure (simulating the Apollo heat shield) impacting land. Analytical programs should be developed to account for soil elasticity and deformation of shell structure.

SUGGESTED DESIGN, DEVELOPMENT, AND QUALIFICATION PROGRAM

1. Detail Design and Analysis

    a. Prepare design specifications

    b. Prepare drawings

        (1) Impact attenuation mechanisms

        (2) Structural modifications

        (3) Systems relocation

    c. Build a MISDAS/Vehicle integration mockup

    d. Modify dynamic landing stability program to include:

        (1) Realistic soil characteristics

        (2) Dig-in conditions

        (3) Real strut characteristics - strut optimization

    e. Perform dynamic analysis

    f. Perform structural analysis

    g. Perform detailed test programs

        (1) Development

        (2) Qualification

        (3) Acceptance

    h. Prepare manufacturing plan

        (1) Tooling

        (2) Facilities

Suggested steps apply to the two concepts studied in Contract NAS9-4915 - Phase II. Areas where detail design and analysis are necessary include:

(a) Ablative and steel heat shield redesign

(b) Impact attenuation members installation, deployment, and operation

(c) Shock struts

(d) Heat shield support members

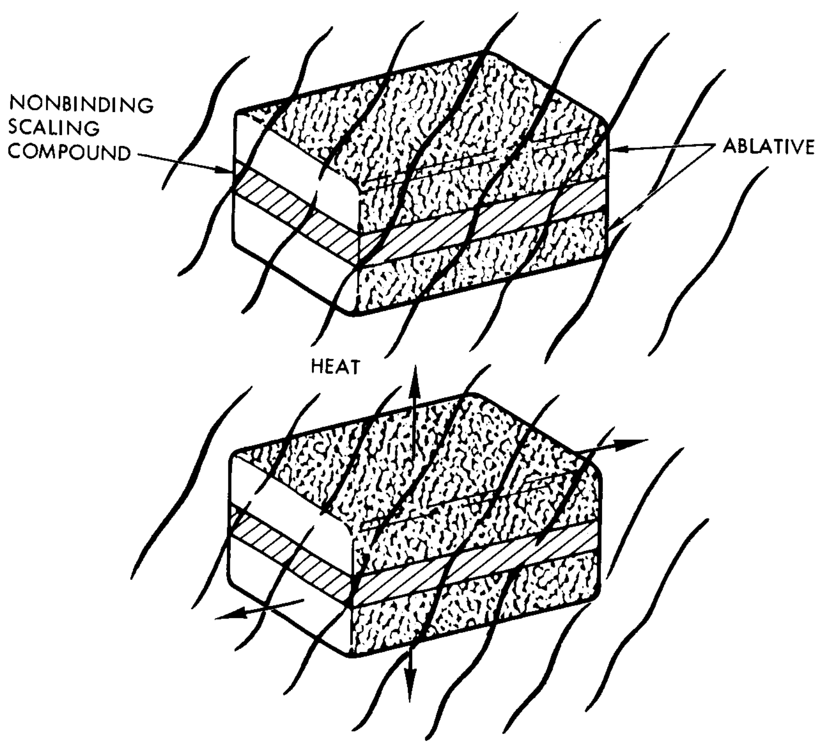
(e) Command module modified structure

2. System Development

a. Segmented ablative heat shield tests (see sketch below)

(1) Exposure of joined ablative samples to space environment

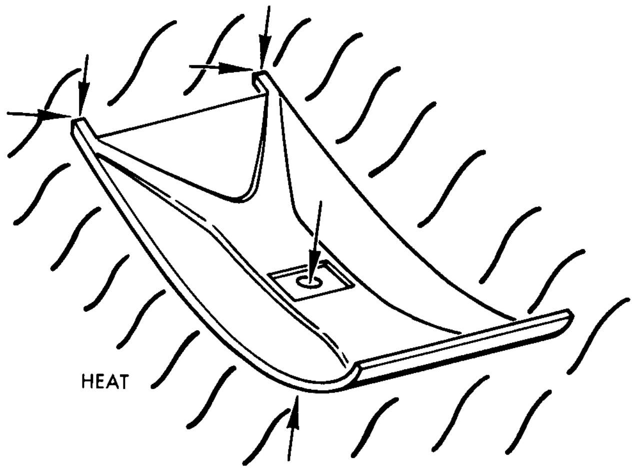
(2) Exposure to entry conditions, including thermal-structural tests of joined samples to determine effects of strain, erosion, material degradation, bonding material expansion, hardening and softening of thermal protection materials, heat shield, landing shoes, and skids deployment forces, and land and water impact



b. Thermal-structural tests of segmented steel heat shield (reduced scale model). See sketch below.

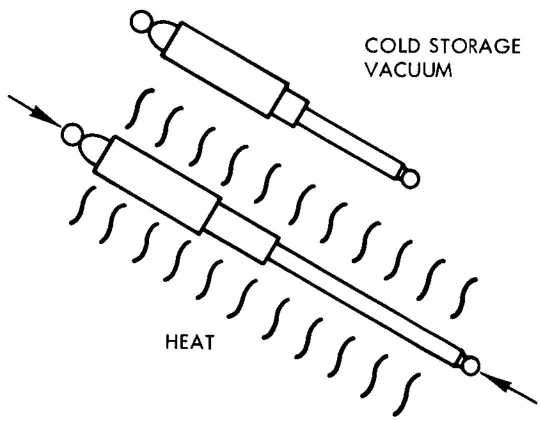
(1) Thermal effects of space and entry conditions: strain, distortion

(2) Structural effects of entry, deployment, and landing



c. Shock absorber system. See sketch below.

(1) Space environment effects (temperature, vacuum) on seals, structural materials, and fluids



(2) Load - stroke characteristics required by dynamic landing

(3) Reusability requirements

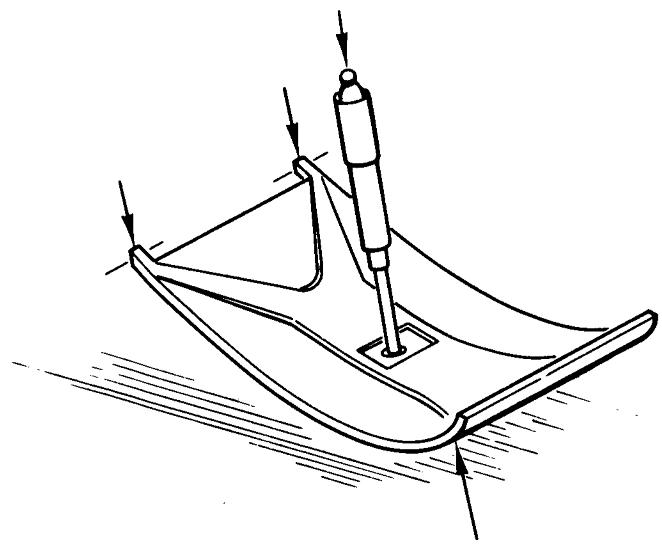
d. Landing energy absorption unit tests (assembly of heat shield and deployed or undeployed struts). See sketch below.

(1) Space environment effects on joints, bearings, seals, etc.

(2) Entry conditions effects on unit

(a) Thermal and load induced deflections and stresses

(b) Thermal effects on structural and sealing compound materials



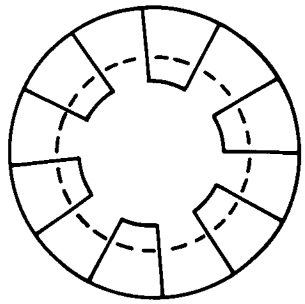
(3) Land and water landing. See sketch .

(a) Total unit energy absorption characteristics

(b) Deformations caused by landing on different soils

(c) Energy absorption characteristics on water landings (deployed and undeployed units)

e. Segmented heat shield tests (reduced scale)



(1) Mechanical and thermal stresses and deflections

(2) Entry loads

(3) Land landing impact (deployed system)

(4) Water landing impact (deployed and undeployed system)

f. Scaled spacecraft model with MISDAS installed tests

(1) Land landing stability

(2) Water landing stability

(a) Deployed system

(b) Undeployed system

(c) Flotation stability

3. Qualification Test Plan

a. Install MISDAS on Apollo boilerplate or used spacecraft

b. Land drop tests (MISDAS deployed)

(1) Mechanical integrity of support structures, energy absorption system, heat shield (deflections)

(2) Stability verification

(3) Crew g limits verification

c. Water impact drop tests

(1) Crew g limits verification

(2) Floating stability

(3) Command module water tightness verification

d. Water impact drop tests (MISDAS not deployed)

(1) Crew g limits verification

(2) Structural integrity

(3) Floating stability

(4) Command module water tightness verification

e. Refurbishment and reusability

(1) Land and water impact effects on permanent structure, MISDAS attach structure, energy absorption components, steel heat shield fixed portions, steel heat shield rings, hinges, and moving portions

REFERENCES

1. Bernstein, A. I. and L. A. Harris. Mechanical Impact System Design for Advanced Spacecraft (MISDAS); Phase I - Design Concept Selection. NAA S&ID, SID 65-1205 (20 September 1965).

2. MIL-HDBK-5. (Rev. November 1965).

3. MIL-HDBK-17. (Rev. June 1965).

4. S&ID Structures Manual. NAA S&ID, SID 543-G-11 (Rev. 15 Dec. 1964).

5. Apollo Requirements Manual, ARM-6. NAA S&ID, SID 64-183 (Rev. 9 Dec. 1965).

6. Gaskets and Parts of Silicone Rubber. AVCO Corp., RAD M70113 (Rev. 12 Oct. 1965).

7. "LEGGED," A Fortran IV Computer Program for the Solution of Legged Vehicle Impact Dynamics. NAA S&ID, SID 66-278.

8. Final Mass Properties Report, AES Preliminary Design Phase. NAA S&ID, SID 65-1532 (18 Dec. 1965).

9. Monthly Weight and Balance Report for the Apollo Spacecraft. NAA S&ID, SID 62-99-43 (1 Sep. 1965).

10. 6DØF, A Fortran IV Computer Program for the Solution of Apollo-Type Vehicle Impact Dynamics. NAA S&ID, SID 66-279.

11. Apollo Materials and Producibility. NAA S&ID Bulletin No. 16.

12. Aerospace Structural Materials Application Handbook (1965) AF 33(616)-7792.

APPENDIX A

STRUCTURAL ANALYSIS CALCULATIONS

This appendix presents the structural analysis calculations performed in support of Contract NAS9-4915, Modification 2, dated 22 December 1965.

This analysis is based on Figures 4, 5, 13, and 14, and the Guidelines, Constraints, and Design Criteria section of this report. Summaries of loads and margins of safety are included in this report. Allowable stresses are given in Appendix C.

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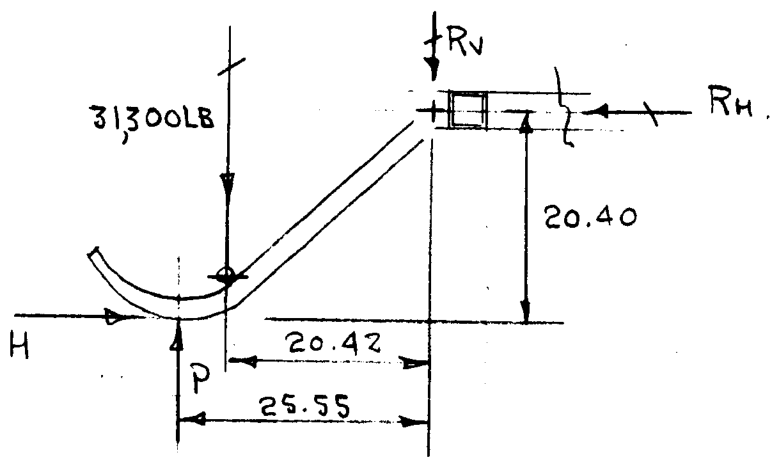
STRUT LOADS

MAX STRUT LOAD = 31,300 LB THIS LOAD IS BASED ON ANALYSIS OF STABILITY AND IMPACT FORCE ATTENUATION. (REF REPORT SID 66-106 PAGE 31)

FACTORS USED IN ANALYSIS.

FOR DEPLOYABLE LEG 1.00
FOR SHOCK STRUT AND ALL OTHER STRUCTURE 1.33



$$P = \frac{31{,}300\,(20.42)}{25.55-(.35)(20.40)} = 34{,}700 \text{ LB.}$$

$$H = 34{,}700\,(.35) = 12{,}120 \text{ LB}$$

$$R_V = 34{,}700 - 31{,}300 = 3{,}400 \text{ LB.}$$

$$R_H = \quad 12{,}120 \text{ LB}$$

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STRUT LOADS
"H" ACTING OUTBOARD.

$$P = \frac{31{,}300\,(20.42)}{25.55 + (.35)(20.4)} = 19{,}500 \text{ LB}$$

$$H = (.35)\,19{,}500 = 6{,}840 \text{ LB}$$

$$R_V = 31{,}300 - 19{,}500 = 11{,}800 \text{ LB}$$

$$R_H = 6840 \text{ LB}$$

STRUT LOADS WHEN H = 0

$$P = \frac{31{,}300\,(20.42)}{25.55} = 25{,}100 \text{ LB}$$

$$R_V = 31{,}300 - 25{,}100 = 6{,}200 \text{ LB}$$

$$R_H = 0 \text{ LB}$$

STRUT LOADS WHEN H ACTS AT 45° (INBOARD)

$$P = \frac{31{,}300\,(20.42)}{25.55 - (.35)(.707)(20.4)} = 31{,}200 \text{ LB}$$

$$H = .35\,(31{,}200) = 10{,}900 \text{ LB}$$

$$R_V = 100 \pm \frac{(.707)\,10{,}900\,(20.4)}{23.375} = 6750 \text{ LB}$$

$$R_H = \frac{(.707)\,10{,}900\,(25.55)}{23.375} + \frac{.707(10{,}900)}{2} = 12{,}310 \text{ LB (MAX)}$$

STRUT LOADS WHEN H ACTS AT 45° (OUTBOARD)

$$P = \frac{31{,}300\,(20.42)}{25.55 + (.35)(.707)(20.4)} = 21{,}000 \text{ LB}$$

$$H = .35\,(21{,}000) = 7340 \text{ LB}$$

$$R_V = 5150 \pm (.707)\,7340\,(20.4)/23.375 = 9{,}680 \text{ LB (MAX)}$$

$$R_H = \frac{.707\,(7340)\,(25.55)}{23.375} + \frac{(.707)\,7340}{2} = 8{,}250 \text{ LB}$$

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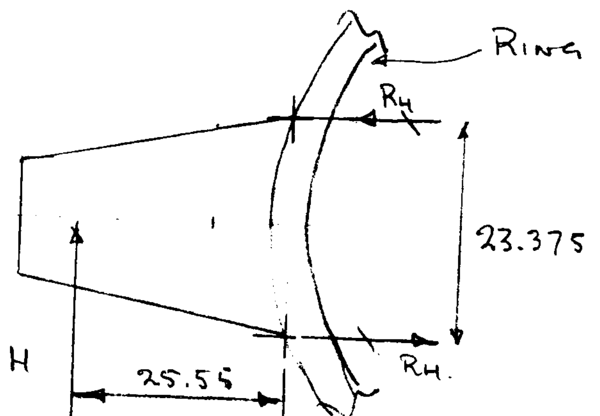
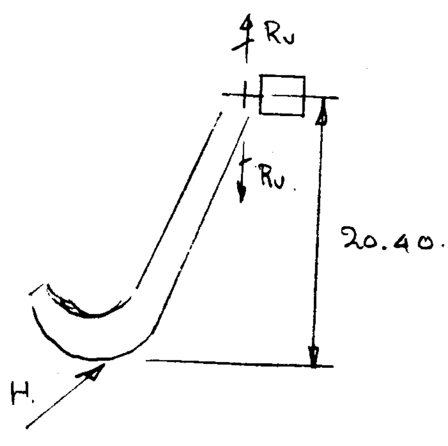
SIDE LOAD. ('H' ACTING AT 90°.)



HINGE REACTIONS (IN THE PLANE OF THE RING.)

$$R_H = \frac{H(25.55)}{23.375} = \frac{.35(25,100)(25.55)}{23.375}$$

$$= 9,630 \text{ LB.}$$



HINGE REACTIONS (OUT OF THE PLANE OF THE RING).

$$= \frac{H(20.4)}{23.375} = \frac{8,420}{23.375}(20.4) = 7360 \text{ LB}$$

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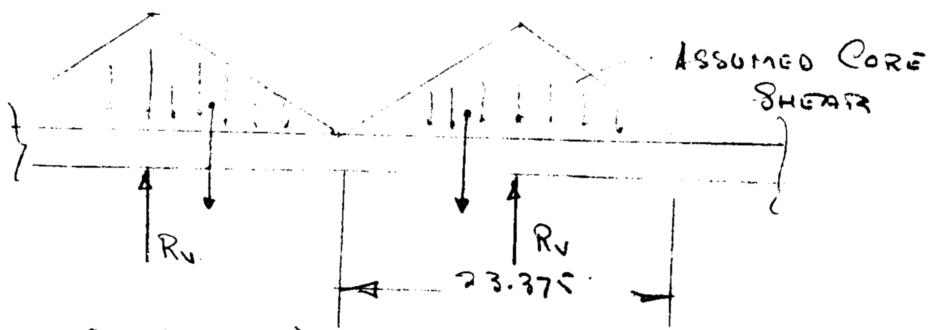
RING AT 44" RAD.

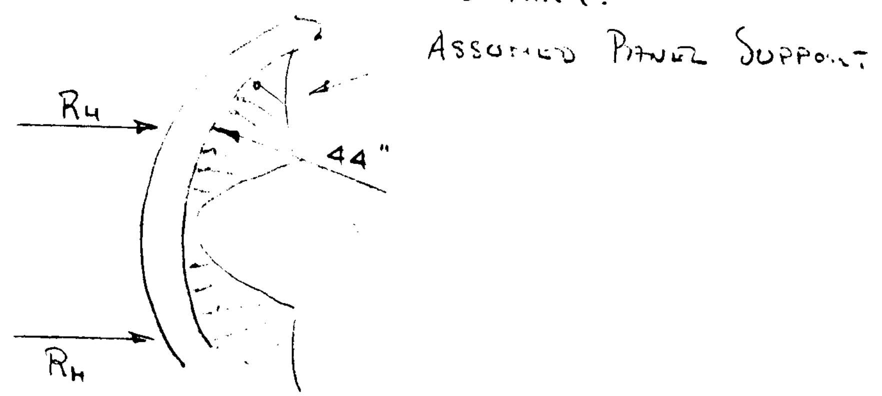
BENDING OUT OF THE PLANE OF THE RING.



$$M = \frac{R_V(23.375)}{12} = \frac{9{,}680(23.375)}{12}$$

$$= 18{,}800 \text{ LB. INS}$$

BENDING IN THE PLANE OF THE RING.



$$M = \frac{R_H(23.375)}{12} = \frac{12310\ (23.375)}{12}$$

$$= 24{,}000 \text{ LB INS.}$$

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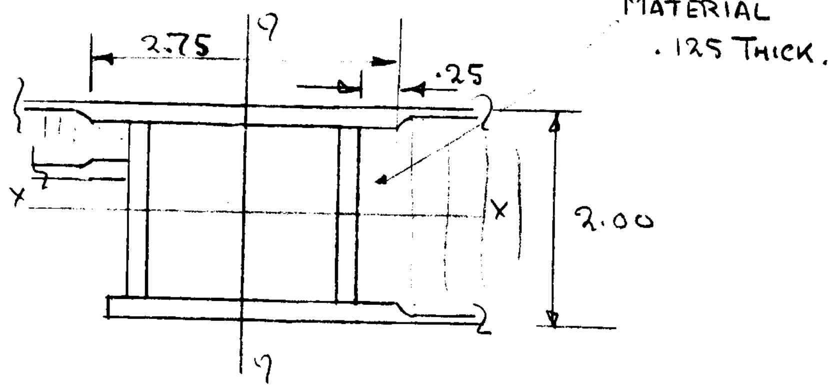
RING AT 44" RADIUS

SECTION PROPERTIES.



I ABOUT XX

$$= 2.75(.125)(.938)^2(2) = .603$$
$$+ .25(1.75)^3/12 = .112$$
$$.715$$

I ABOUT YY

$$= 1.75(.125)(1.062)^2(2.) = .491$$
$$+ .25(2.75)^3/12 = .435$$
$$.926$$

"H" ACTING AT 45° OUTBOARD

$$f_B = \frac{18,800(1)}{.715} + \frac{8250(23.375)(1.375)}{12(.926)}$$
$$= 26,300 + 23,900$$
$$= 50,200 \text{ PSI}$$

AFTER WELD ALLOWABLE AT 600° = 77,000 PSI

$$MS = \frac{77,000}{50,200(1.33)} - 1 = 0.15$$

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RING AT 44" RADIUS.
"H" ACTING AT 45° INBOARD

RING STRESS $f_B = \frac{M_Y c}{I_Y} + \frac{M_X c}{I_X}$

$= \frac{24{,}000\ (1.375)}{.926} + \frac{6750\ (23.375)\ (1)}{12\ (.715)}$

$= 35{,}700 + 18{,}350$

$54{,}050$ PSI

$MS = \frac{77{,}000}{54{,}050\ (1.33)} - 1 = 0.07.$

SHEAR STRESS ON RING.

TORQUE $= 2.12\ (5900) = 12{,}500$ LB INS.

$q = \frac{T}{2A} = \frac{12{,}500}{2(2)(2.25)} = 1390$ LB/IN.

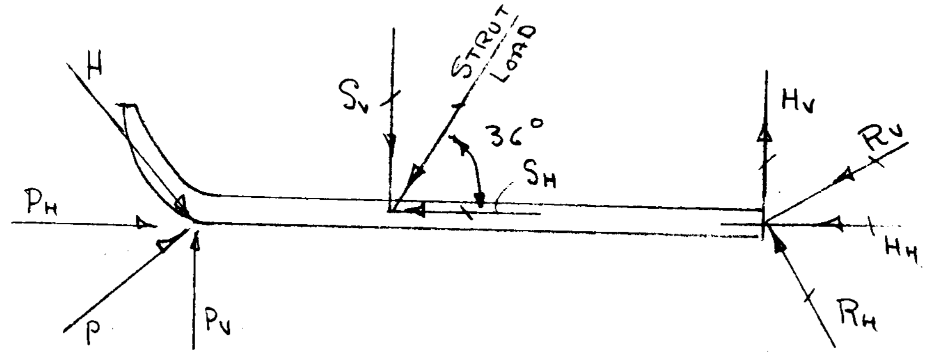
$f_s = \frac{1390}{.125} + \frac{5900}{1.75\ (.25)}$

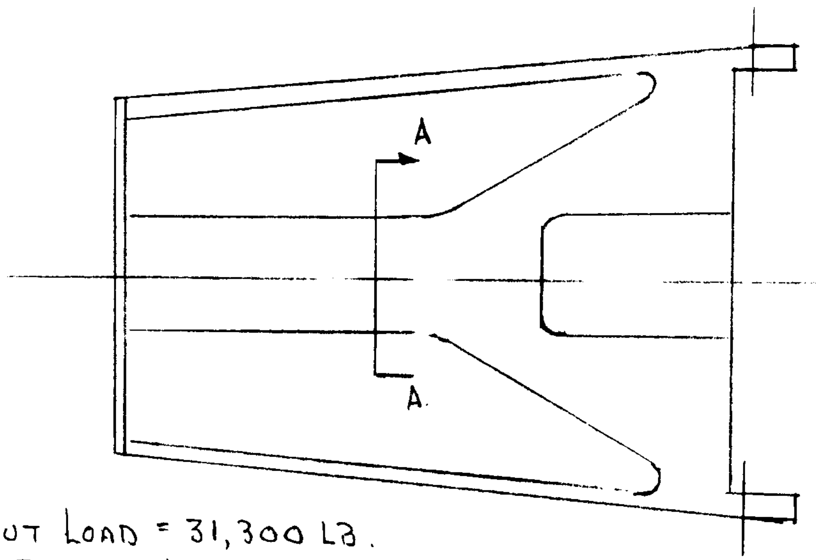
$= 11{,}100 + 13{,}450 = 24{,}550$ P.S.I.

AFTER WELD SHEAR ALLOWABLE $= 46{,}200$ PSI AT 600° F

$MS = \frac{46{,}200}{24{,}550\ (1.33)} - 1 = 0.41.$

DEPLOYABLE LEG.





STRUT LOAD = 31,300 LB.

$P = 34,700$ LB.

$H = 12,120$ LB

$R_H = 12,120$ LB

$R_V = 3,400$ LB.

$$H_H = R_H \cos 36^\circ + R_V \sin 36^\circ$$
$$= 12,120(.809) + 3400(.588)$$
$$= 9800 + 2000 = 11,800 \text{ LB.}$$

$$H_V = R_H \sin 36^\circ - R_V \cos 36^\circ$$
$$= 12,120(.588) - 3400(.809)$$
$$= 7130 - 2740 = 4390 \text{ LB.}$$

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DEPLOYABLE LEG

$$P_V = P\cos 36 - H\sin 36$$
$$= 34{,}700(.809) - 12{,}120(.588)$$
$$= 28{,}000 - 7140 = 20{,}860 \text{ LB.}$$

$$P_H = P\sin 36 + H\cos 36$$
$$= 34{,}700(.588) + 12{,}120(.809)$$
$$= 20{,}400 + 9800 = 30{,}200 \text{ LB.}$$

BENDING MOMENT SECTION AA.

$$M = 4390(26.0) = 114{,}000 \text{ LB INS.}$$

END LOAD = 30,200 LB (COMPRESSION).

SHEAR = 20,860 LB.

TORQUE (H ACTING AT 90°)

$$= \frac{25{,}100(.35)(1.436)}{2(.809)} = 7800 \text{ LB INS}$$

SECTION AA

COMPRESSIVE ALLOWABLE OF .156 STEEL PLATE AT 600°F.

$$\sigma_{CR}/\eta = \frac{K\pi^2 E}{12[1-\mu^2]}\left(\frac{t}{b}\right)^2$$

$$= \frac{6.98(\pi)(25)(10)^6}{12(1-.33^2)}\left(\frac{.156}{6}\right)^2$$

$$= 109{,}000 \text{ PSI}$$

PLASTICITY CORRECTION

$$= 105{,}000 \text{ P.S.I.}$$

REF STRUCTURES MANUAL PG. 6.20.01. (REFERANCE 4.)

NOTE:- COMPRESSIVE ALLOWABLES FOR STRESS LEVELS ABOVE THE MATERIAL YIELD POINT ARE SUBJECT TO BOTH ELASTIC AND PLASTIC DEFORMATIONS. TO COMPENSATE FOR THE PLASTIC DEFORMATION A FACTOR IS APPLIED BASED ON TEST VALUES.

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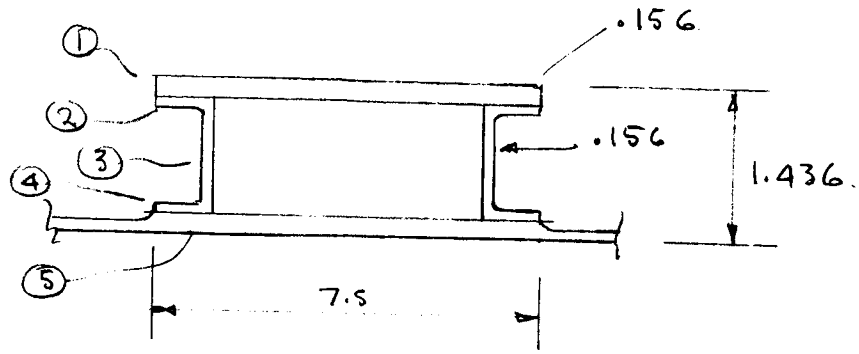
DEPLOYABLE LEG

SECTION A A



SECTION PROPERTIES

ITEM	AREA	Y_{NA}	$A\,Y_{NA}^2$	I_o
1	1.170	0.64	0.480	.0024
2	.234	0.484	0.0547	.0005
3	.350	0	.0	.0359
4	.234	0.484	0.0547	.0005
5	1.170	0.64	0.480	.0024
	3.158		1.0694	.0417
				1.0694
				1.1111

$$f_s = \frac{20,860}{.350} = 59,800 \text{ P.S.I.}$$

$$f_c = \frac{114,000(.718)}{1.1111} + \frac{30,200}{3.158}$$

$$= 74,000 + 9,600$$

$$= 83,600 \text{ PSI}$$

$$MS = \frac{105,000}{83,600} - 1 = 0.25$$

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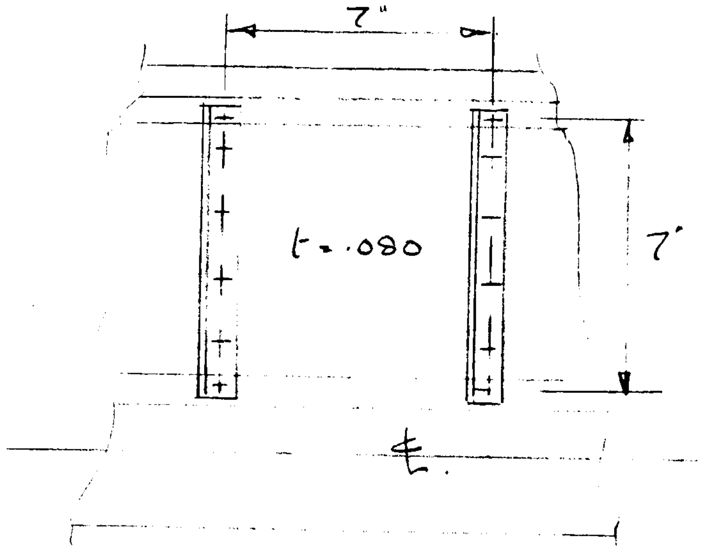
EXTENDABLE SHOE SKIN.

CONDITION :- AERODYNAMIC LOADING AT ENTRY.

MAXIMUM PRESSURE = 25.5 PSI.



$$f_{MAX} = \frac{.75(\omega)(b)^2}{t^2(2.61)}$$

$$= \frac{.75(25.5)(7)^2}{(.080)^2(2.61)} = 55,000 \text{ PSI.}$$

M.S. HIGH

PANEL DEFLECTION

$$y = \frac{.1422\,\omega b^4}{E t^3 (3.21)}$$

$$= \frac{.1422(17)(2400)}{25(10)^6\, 5.12(10)^{-4}(3.21)} = 0.141''$$

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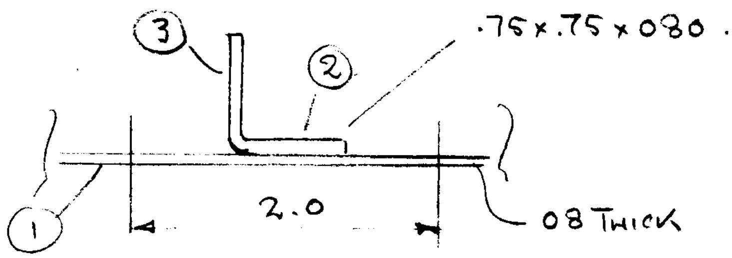
EXTENDABLE SHOE SKIN STIFFENERS.

SECTION PROPERTIES.



ITEM	AREA	Y_{XX}	AY_{XX}	Y_{NA}	AY_{NA}^2	I_o
1	.160	.040	.0064	.106	.00179	.00008
2	.0575	.120	.0069	.026	.00004	.00003
3	.06	.455	.0272	.309	.00574	.00281
	.2775		.0405		.00757	.00292
						.00757
						.01049 INS^4

$$Y_{NA} = \frac{.0405}{.2775} = .146$$

$$M = \frac{w\ell^3}{8} = \frac{25.5(7)^3}{8} = 1095 \text{ LB INS}$$

$$f_B = \frac{1095(.624)}{.01049} = 71,600 \text{ P.S.I.}$$

MS HIGH

SHEAR FLOW AT ATTACHMENTS

$$q = \frac{VQ}{I} = \frac{25.5(24.5)}{.01049} = 1055$$

3/16 HUCKS AT 2" CENTERS

$$MS = \frac{(2)1055}{2620} - 1 = 0.24.$$

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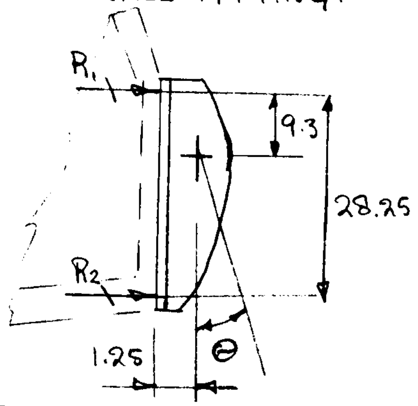
SIDEWALL FITTING.



CONDITION	Θ	SIN	COS
2	31.5	.522	.853
3	25.25	.426	.904
4	17.5	.301	.954
5	9.75	.168	.985

STRUT LOAD 31,300 LB LIMIT
31,300 (1.33) = 41,600 LB ULT.

RESOLVING STRUT LOAD.

COND	VERTICAL	HORIZONTAL	R_1	R_2
2	35,400	21,700	16,160	5540
3	37,600	17,750	13,600	4150
4	39,600	12,580	10,120	2460
5	41,000	7,000	6,520	480

LOAD ON BOND CRITICAL CONDITION 5

$$q = \frac{41000}{29} = 1415 \text{ LB/IN (AVERAGE)}$$

ASSUMING TRIANGULAR DISTRIBUTION

$$q_{MAX} = 1415(2) = 2830 \text{ LB/IN.}$$

BASE OF FITTING 3.0 WIDE

$$\text{BOND STRESS} = \frac{2830}{3.0} = 943 \text{ P.S.I}$$

BOND ALLOWABLE AT 200°F = 1320 PSI

$$MS = \frac{1320}{943} - 1 = 0.41$$

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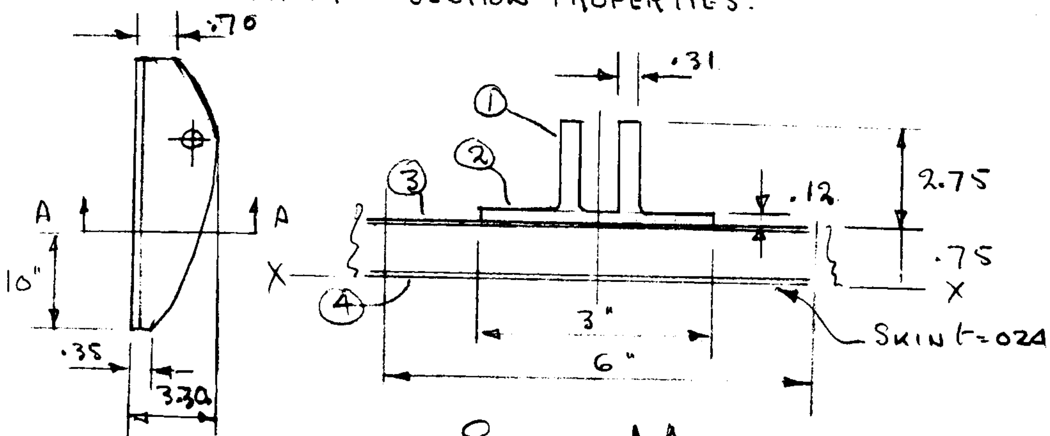
SIDEWALL FITTING - SECTION PROPERTIES.



SECTION AA.

ITEM	AREA	y_{xx}	Ay_{xx}	y_{NA}	Ay_{NA}^2	I_o
1	1.630	2.185	3.560	.445	.322	.940
2	.360	.810	.291	.930	.312	.0004
3	.144	.738	.106	1.002	.144	.0
4	.144	.012	.002	1.728	.430	.0
	2.278		3.959		1.208	.9404

$$Y_{NA} = \frac{3.959}{2.278} = 1.740$$

$$\begin{array}{r} .9404 \\ \underline{1.208} \\ 2.1484 \end{array}$$

CONDITION 2

$$q_{MAX} = \frac{35,400}{29}(2.) = 2450 \text{ LB/IN.}$$

SECTION AA

$$\text{END LOAD} = \frac{2450}{2}(5) = 6130 \text{ LB. (TENSION).}$$

$$M = 5540(10) = 55,400 \text{ LB INS.}$$

$$f_T = \frac{55,400(1.76)}{2.148} + \frac{6130}{2.278}$$

$$= 45,400 + 2,700 = 48,100 \text{ P.S.I.}$$

2014 T6 INNER SKIN ALLOWABLE 60,000 PSI

$$MS = \frac{60,000}{48,100} - 1 = 0.24.$$

SIDEWALL FITTING

SHEAR AT FORWARD END. (CONDITION 2.)

$$f_s = \frac{16,160}{.70\,(.62)} = 37,200 \text{ PSI}$$

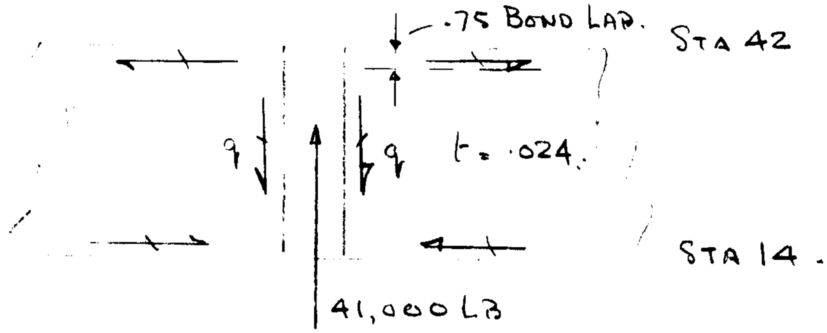
$$MS = \frac{40,000}{37,200} - 1 = 0.07$$

SHEAR AT AFT END.

$$f_s = \frac{5540}{.25\,(.62)} = 35,800 \text{ PSI}$$

$$MS = \frac{40,000}{35,800} - 1 = 0.12$$

AFT SIDEWALL SKIN INNER STRUCTURE:
CONDITION 5



$$q_{AVERAGE} = \frac{41,000}{28\,(2)} = 730 \text{ LB/IN}$$

ASSUME TRIANGULAR DISTRIBUTION

$$q_{MAX} = 730\,(2) = 1460 \text{ LB/IN.}$$

$$f_s = \frac{1460}{.048} = 30,500 \text{ PSI}$$

$$MS = \frac{38,000}{30,500} - 1 = 0.25$$

BOND STRESS
AT STA 42.

$$f_{BOND} = \frac{730}{.75} = 975 \text{ PSI}$$

$$MS = \frac{1320}{975} - 1 = 0.35$$

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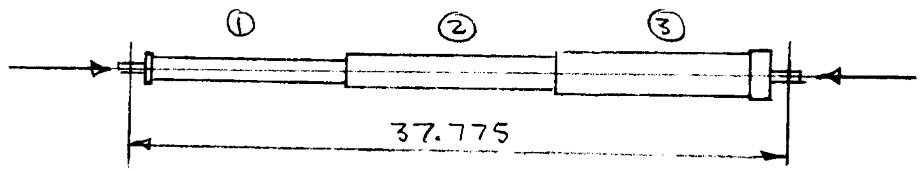
SHOCK STRUT

LOAD = 31,300 (1.33) = 41,700 LB (ULT) REF PG 1.1



ITEM	THICKNESS	DIAM	AREA	I	ρ	LENGTH
①	.100	1.75	.518	.1765	.585	12.5
②	.080	2.25	.550	.3210	.764	11.0
③	.080	2.75	.674	.600	.945	14.2

$$\frac{l}{\rho} = \frac{12.5}{.585} + \frac{11.0}{.764} + \frac{14.2}{.945} = 50.4$$

TYPICAL STAINLESS STEEL ALLOWABLES AT 600F

COLUMN ALLOWABLE = 91,000 P.S.I

$$f_c = \frac{41,700}{.518} = 81,000 \text{ PSI}$$

$$MS = \frac{91,000}{81,000} - 1 = 0.12$$

WORKING PRESSURE

PISTON AREA $= \pi(1.295)^2 = 5.27 \text{ INS}^2$

PRESSURE $= \frac{41,700}{5.27} = 7910$ P.S.I

STRESS IN WALL ITEM ③

$$f_T = \frac{PR}{t} = \frac{7910\,(1.295)}{.08} = 128,000 \text{ PSI}$$

$$MS = \frac{156,000}{128,000} - 1 = 0.22$$

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AFT HEAT SHIELD STRUCTURE

WATER IMPACT CONDITION.

ASSUMPTIONS

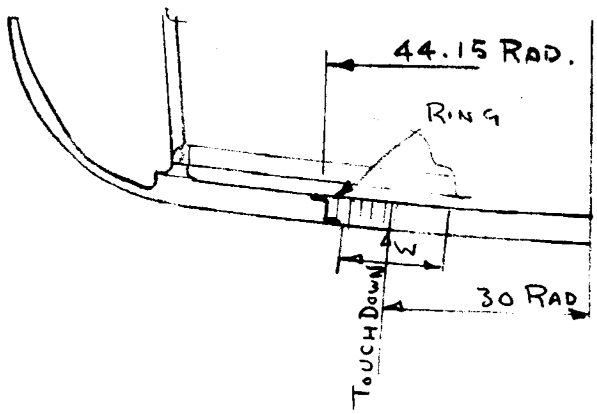
IMPACT ANGLE 10° AT 15 ft/SEC.

IMPACT FORCE 8.0 g.

LOADS CONSIDERED ULTIMATE.

W = WETTED AREA.

WEIGHT 10,600 LB.



$$\text{PRESSURE} = \frac{\text{WEIGHT (g)}}{\text{WETTED AREA}}.$$

CONDITION	WETTED RAD	WETTED AREA	PRESSURE ON H/S
①	14.15	630 INS²	135 PSI
* ②	35.00	3800	22.4 PSI
* ③	50.00	7900	10.75 PSI

CONDITIONS ② AND ③ ARE LESS CRITICAL THAN THE ENTRY AIR LOADS ON THE IMPACT SIDE.
(AIR LOAD = 17(1.5) = 25.5 PSI ULT.)

CONDITION ①

$$\text{CORE SHEAR} = \frac{W(g)}{2\pi R} = \frac{10{,}600\,(8)}{2\pi\,(14.15)} = 995 \text{ LB/IN}$$

$$\text{SHEAR STRESS} = \frac{995}{2} = 497 \text{ P.S.I}$$

CORE ALLOWABLE

3/16 CELL .0015 FOIL @ 600°F = 260 PSI

MS = 0.73.

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AFT HEAT SHIELD STRUCTURE
WATER IMPACT COND 1 (CONT^D)

LINE LOAD ON RING.

$$\text{MEAN} = \frac{10600(8)}{\pi\, 88.3} = 305 \text{ LB/IN.}$$

$$\text{MIN} = \frac{305(14.15)}{44.15} = 97.8 \text{ LB/IN.}$$

$$\text{MAX} = \frac{305(74.15)}{44.15} = 515 \text{ LB/IN.}$$

BENDING MOMENT ON CENTER PANEL

$$\text{MAX B.M} = 515(14.15) - \left(\frac{305+97.2}{2}\right)(7.07)$$

$$= 7300 - 2170 = 5130 \text{ LB INS.}$$

ASSUME SKIN THICKNESS = .020.

$$f_B = \frac{5130}{2(.020)} = 127{,}500 \text{ PSI.}$$

ALLOWABLE = 135,000 P.S.I.

BM AT CENTER OF H/S.

$$= 44.15(97.8) = 4300 \text{ LB INS.}$$

SKIN THICKNESS AT CENTER = .016

$$f_B = \frac{4300}{2(.016)} = 134{,}000 \text{ P.S.I.}$$

ALLOWABLE 135,000

$$MS = \frac{135{,}000}{134{,}000} - 1 = 0.01$$

MAX BM

$$= 515(28.3) - (515+97.2)(14.15) = 5900$$

$t = .022$

$$f_B = \frac{5900}{2(.022)} = 134{,}000 \text{ PSI}$$

$$MS = \frac{135{,}000}{134{,}000} - 1 = 0.01$$

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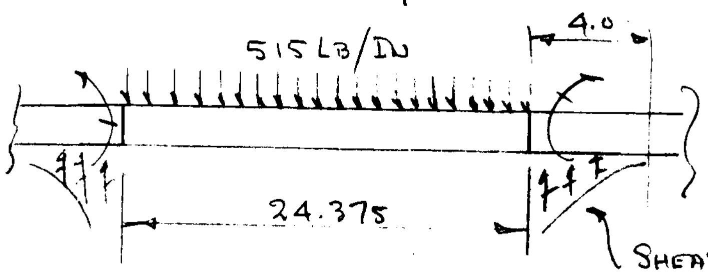
AFT HEAT SHIELD STRUCTURE

WATER IMPACT CONDITION ①

THE 88" DIA RING BEAMS THE LOAD ON THE CENTER PANEL ACROSS THE LEG BAYS.



EQU. SPAN $= 24.375 + (.66)40$
$= 27.03$

$M = w\ell^2/12$
$= 515(24.375)(27.03)/12 = 28{,}200$ LB INS.

$f_B = \dfrac{28{,}200}{.849}(1) = 33{,}300$ P.S.I.

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AFT HEAT SHIELD STRUCTURE

WATER IMPACT COND ①. (RING STRESSES CONTINUED)

HOOP TENSION ON RING $= \frac{PR}{2} = \frac{113\,(44.15)}{2}$

$= 2500$ LB.

RING STRESS (TOTAL)

$f_B = 33{,}300 + \frac{2500}{1.47}$

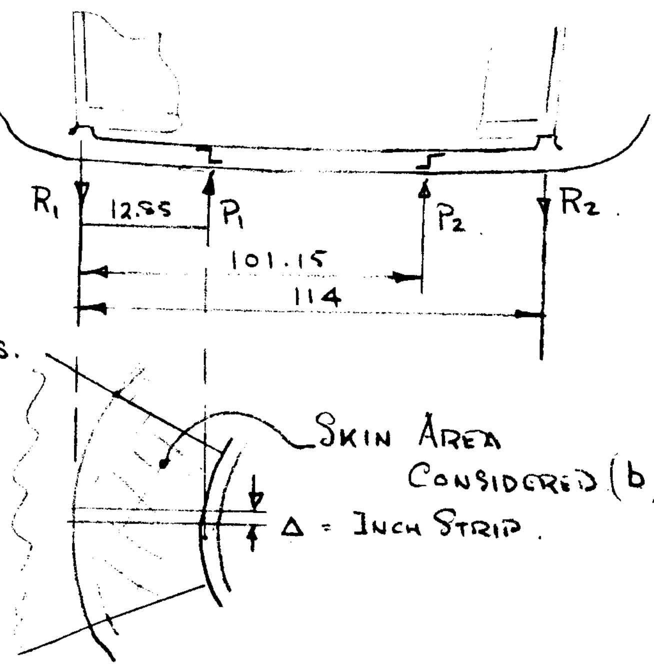
$= 33{,}300 + 1700 = 35{,}000$ P.S.I.

HIGH MARGIN.

BENDING ON SKINS BETWEEN RING AND INNER STRUCTURE SUPPORT

$\Delta P_1 = 515(2) = 1030$ LB.

$\Delta P_2 = 97.8(2) = 195.6$ LB.



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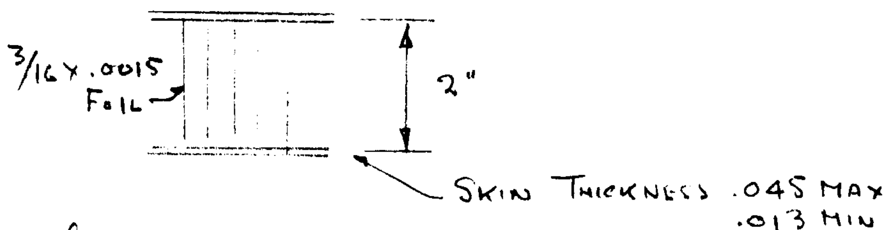
BENDING ON SKIN AREA (b) CONTINUED.

TAKING MOMENTS ABOUT R_1

$$114 R_2 = 101.15(195.6) + (1030)12.85$$
$$= 19{,}850 + 13{,}250$$
$$R_2 = \frac{33{,}100}{114} = 290 \text{ LB.}$$
$$R_1 = 1030 + 195.6 - 290 = 935.6 \text{ LB.}$$
$$M_{MAX} = 935.6(12.85) = 12{,}050 \text{ LB INS.}$$



$$f_B = \frac{12{,}050}{(2).045} = 134{,}000 \text{ PSI}$$

$$MS = \frac{150{,}000}{134{,}000} - 1 = 0.12$$

CORE SHEAR

$$f_s = \frac{1030}{2} = 515 \text{ PSI}$$

$$MS = \frac{860}{515} - 1 = 0.67$$

$$M_{MIN} = 290(12.85) = 3730 \text{ LB INS}$$

$$f_B = \frac{3730}{2(.013)} = 143{,}000 \text{ PSI}$$

$$MS = \frac{150{,}000}{143{,}000} - 1 = 0.05$$

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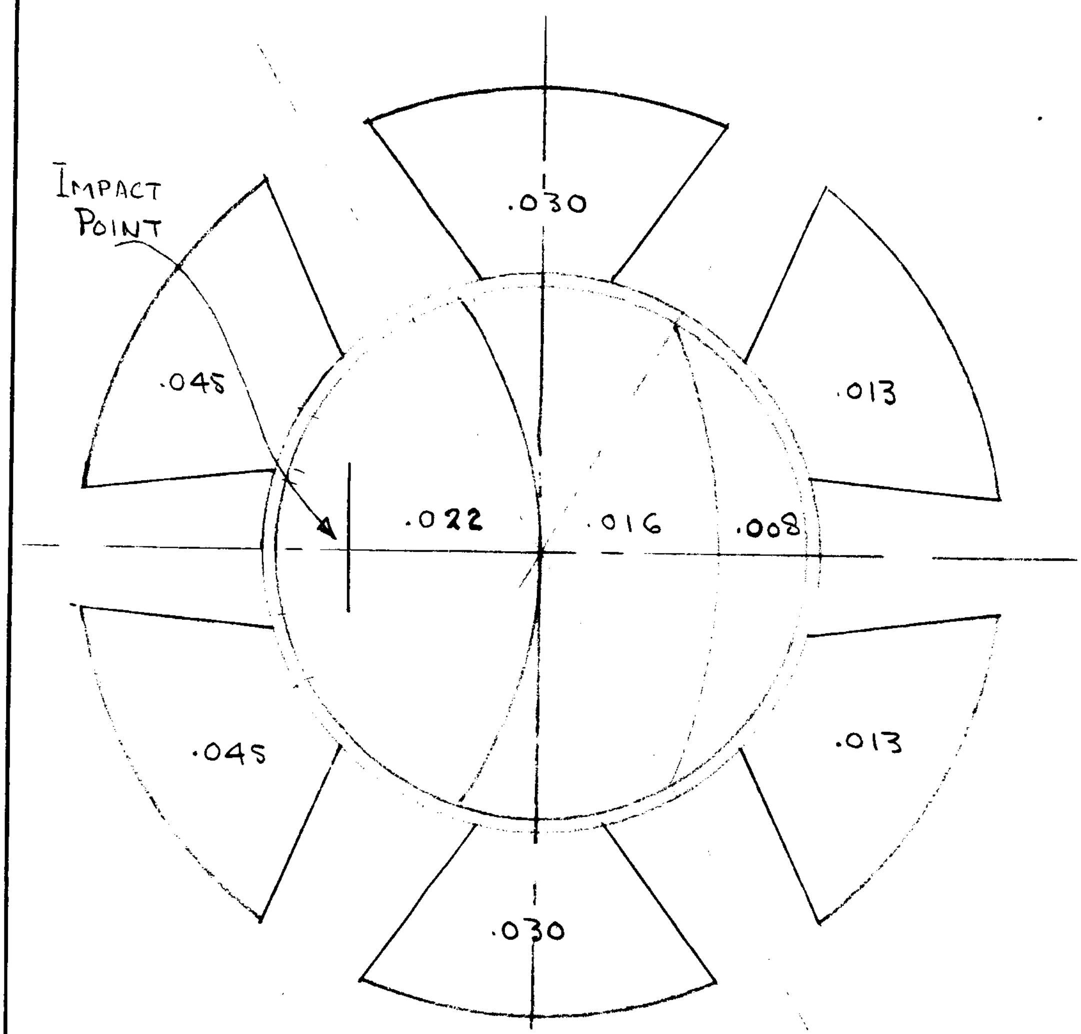
SKIN PROFILE

SCALE 1=24.



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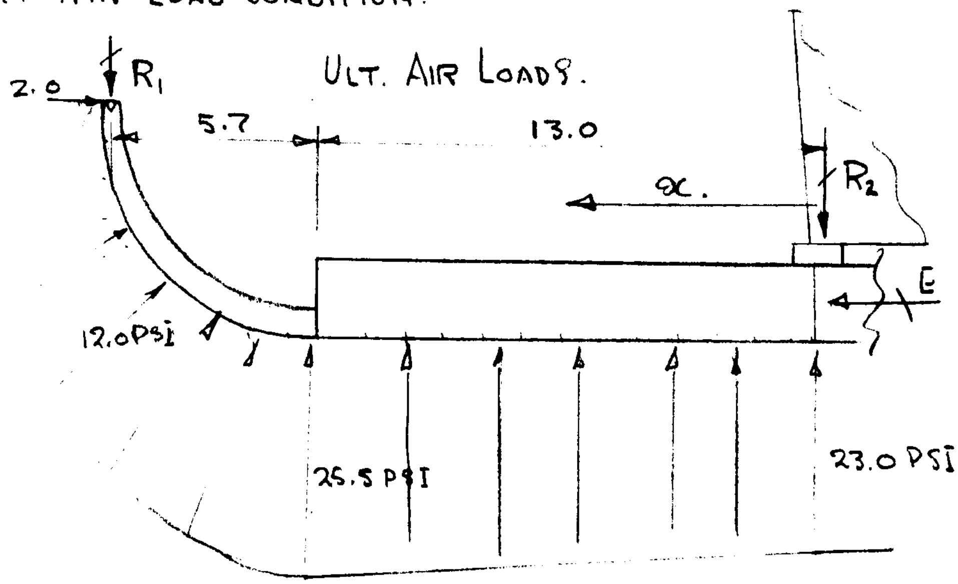
AFT HEAT SHIELD STRUCTURE
ENTRY AIR LOAD CONDITION.



TOTAL VERTICAL LOAD

$$w\ell = \{23(13) + 1.25(13)\} + \{4(9) + 2(16) + 1.7(4.5)\} = 392 \text{ LB.}$$

TOTAL HORIZONTAL LOAD

$$w_y = 4.5(4) + 2(1.7) + 3.5(1.7) = 27.4 \text{ LB.}$$

ASSUME ALL w_y REACTED AT E THEN E = 27.4 LB.

EQUATING DEFLECTIONS.

$$\delta = \frac{R_1 \ell^3}{3EI} = \frac{w\ell^4}{8EI}$$

$$R_1 = 3w\ell/8 = 3(392)/8 = 147 \text{ LB.}$$

$$R_2 = 392 - 147 = 245 \text{ LB.}$$

$M_{x=0}$

$$-147(18.7) + 392(8.28) + 27.4(2.4)$$
$$= -2750 + 3240 + 65$$
$$= 555 \text{ LB INS.}$$

AFT HEAT SHIELD STRUCTURE
ENTRY AIR LOAD CONDITION (CONTINUED)

M AT $x = 12.9$

$$-147(5.8) + 78.5(3.8) + 27.4(2.4)$$
$$= -852 + 299 + 65 = -488 \text{ LB INS}$$

M AT $x = 13.0$

$$-147(5.7) + 76(3.7) + 27.4(2.9)$$
$$= -837 + 281 + 79 = -477 \text{ LB INS}$$

M AT $x = 10$

$$-147(8.7) + 152(4.1) + 27.4(2.4)$$
$$= -1278 + 622 + 65 = -600 \text{ LB INS}$$

STRESS IN SKIN (ON 2" DEEP SECTION)
ASSUME $t = .008$

$$f_c = \frac{600(1)}{2(.008)} + \frac{27.4}{.016} = 39{,}200 \text{ P.S.I}$$

HIGH MARGIN.

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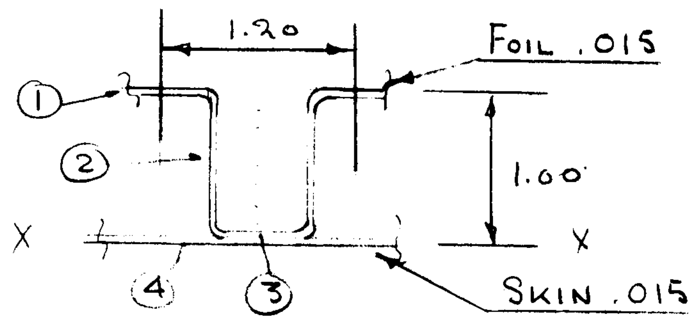
AFT HEAT SHIELD (TOROIDAL SECTION)

ENTRY AIR LOAD CONDITION.



ITEM	AREA	y_{xx}	Ay_{xx}	y_{NA}	Ay_{NA}^2	I_o
1	.009	.993	.00895	.625	.00352	
2	.0286	.507	.0145	.139	.00055	.00218
3	.009	.022	.0002	.346	.00011	
4	.018	.007	.00013	.361	.00235	
	.0646		.02378		.00653	.00218

$$Y_{NA} = \frac{.02378}{.0646} = .368$$

$$\begin{array}{r} .00218 \\ .00653 \\ \hline .00871 \end{array}$$

MOMENT AT $\alpha = 12.9$ = 488 LB INS / IN.

$$f_B = \frac{488(1.2)(.632)}{.00871} = 42,500 \text{ P.S.I.}$$

BUCKLING ALLOWABLE ITEM 1.

$K = 4.0$, $E = 25(10)^6$, $\left(\frac{t}{b}\right)^2 = .000625$

$$\frac{\pi^2}{12[1-\mu^2]} = .914 \qquad \sigma_{CR} = 4(25)(10)^6(.914)(.000625)$$
$$= 57,500 \text{ P.S.I.}$$

BUCKLING ALLOWABLE ITEM 2

$K = 10 \quad \left(\frac{t}{b}\right)^2 = .000274$

$$\sigma_{CR} = 10(25)(10)^6(.914)(.000274) = 56,200 \text{ PSI}$$

$$MS = \frac{57,500}{42,500} - 1 = 0.35$$

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AFT HEAT SHIELD DEFLECTIONS.
WATER IMPACT

FROM R = 44 To R = 57.

$$\delta = \frac{1}{EI}\iint M\,dx\,dx = \frac{1}{EI}\frac{Wx^3}{3}$$

$Wx = 12,050$ LB INS

$EI = 25(10)^6(.045)(2) = 2.25(10)^6$

$$\delta = \frac{12,050(12.85)^2}{3(2.25)(10)^6} = .293 \text{ INCHES.}$$

DEFLECTION OF AREA SUBJECT TO LOAD.

$$\delta = \frac{96WR^2}{144\pi E t^3}$$

SKIN THICKNESS = .022

$I = .024(1)^2(2) = .044$

$I = bd^3/12 \qquad d^3 = \frac{12I}{B} = \frac{.048(12)}{1}$

$= .528$

$$\delta = \frac{96(10,600)(8)(44.00)^2}{144\pi(25)(10)^6(.575)} = 2.610 \text{ INCHES}$$

TOTAL DEFLECTION $= 2.610 + .293$
$= 2.903$ INCHES.

THE DEFLECTED HEAT SHIELD WILL MAKE CONTACT WITH THE INNER STRUCTURE.

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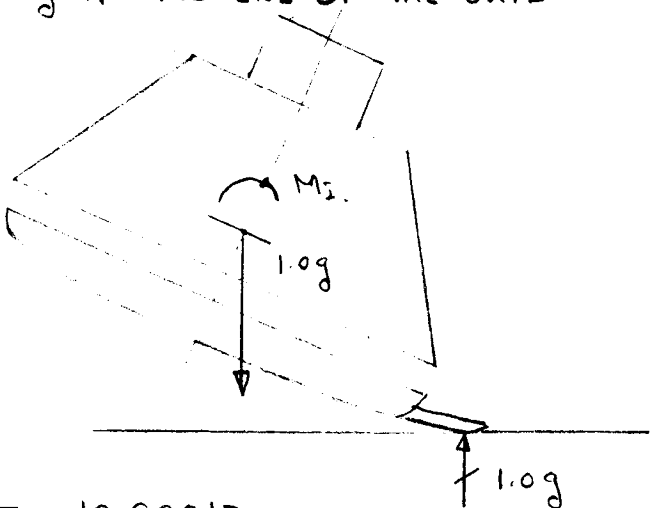
LOAD ON SKIDS

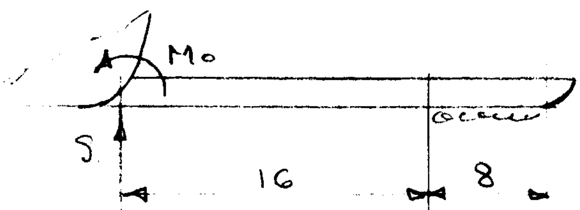
ASSUME MAX TUMBLING LOAD RESULTS IN 1.0g AT THE END OF THE SKID



WEIGHT = 10,600 LB

$1.0g = 10{,}600(1.5)^{*} = 15{,}900$ LB ULTIMATE.

THE ANALYSIS IS BASED ON THE FOLLOWING
1. THE LOAD IS ACTING ON TWO SKIDS
2. THE LOAD IS DISTRIBUTED OVER 8" OF SKID.



$$M_o = \frac{20(15{,}900)}{2} = 159{,}000 \text{ LB INS}$$

$$\text{SHEAR } S = 15900/2 = 7950 \text{ LB.}$$

* NOTE THE ANALYSIS IS BASED ON A LIMIT TO ULTIMATE FACTOR OF 1.50.
MARGINS ARE ALSO SHOWN FOR A FACTOR OF 1.00 ON THE SKIDS AND 1.33 ON THE SUB STRUCTURE

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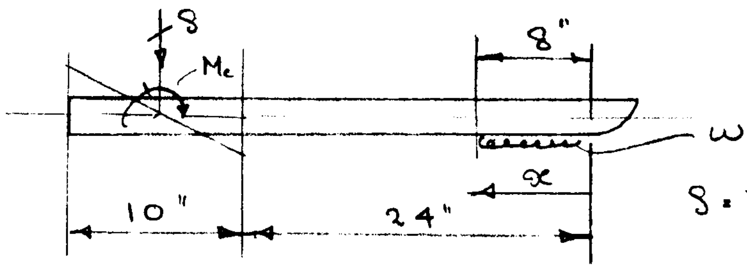
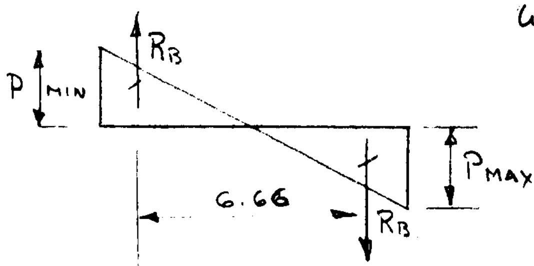
SKID BENDING. BASED ON SOCKET ACTION BETWEEN SKID AND HOUSING.



S = 7950 LB.

$M_e = 7950\,(25) = 198{,}750$ LB INS

$\omega = 7950/8 = 995$ LB/IN.



$$R_B = \frac{198{,}750}{6.66} = 29{,}800 \text{ LB}$$

$$P_{MAX} = \frac{29{,}800}{(.5)\,5.0} + \frac{7950}{10} = 12{,}695 \text{ LB.}$$

$$P_{MIN} = \frac{29{,}800}{(.5)\,5.0} - \frac{7950}{10} = 11{,}105 \text{ LB.}$$

BENDING MOMENT

$x = 4$ $\quad M = \frac{\omega x^2}{2} = \frac{995(4)^2}{2} = 7950$ LB INS.

$x = 5.5$ $\quad M = \frac{995\,(5.5)^2}{2} = 15{,}100$ LB INS

$x = 8$ $\quad M = \frac{995\,(8)^2}{2} = 31{,}800$ LB INS.

$x = 10$ $\quad M = 7950\,(6) = 47{,}800$ LB INS

$x = 24$ $\quad M = 7950\,(20) = 159{,}000$ LB INS.

$x = 29$ $\quad M = M_c/2 = 99{,}375$ LB INS.

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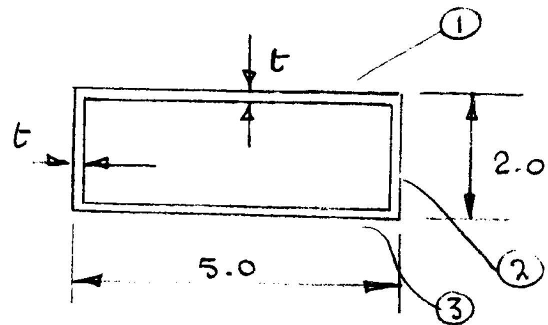
SKID SECTION PROPERTIES



FOR t = 0.060"

ITEM	AREA	Y_{NA}	$A Y_{NA}^2$	I_o
1	.292	.970	.2845	.0001
2	.240	0	0	.0800
3	.292	.970	.2845	.0001
	.824		.5690	.0802
				.5690
				.6492

FOR t = 0.080 I = .865
t = 0.100 I = 1.079
t = 0.120 I = 1.298
t = 0.130 I = 1.408

MATERIAL PH14-8 STEEL OR SIMILAR.
COMPRESSIVE BUCKLING ALLOWABLES. AT 600°F.

t = 0.060 = 25,200 P.S.I.
t = 0.080 = 44,600 P.S.I
t = 0.100 = 70,000 PSI
t = 0.120 = 101,000 P.S.I.
t = 0.130 = 118,000 PSI.

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SKID

MOMENT OF RESISTANCE

FOR t = .060

MR = 25,200 (.6492) = 16,350 LB INS.

t = .080

MR = 44 600 (.865) = 38,600 LB INS

t = .100

MR = 70,000 (1.079) = 75,500 LB INS

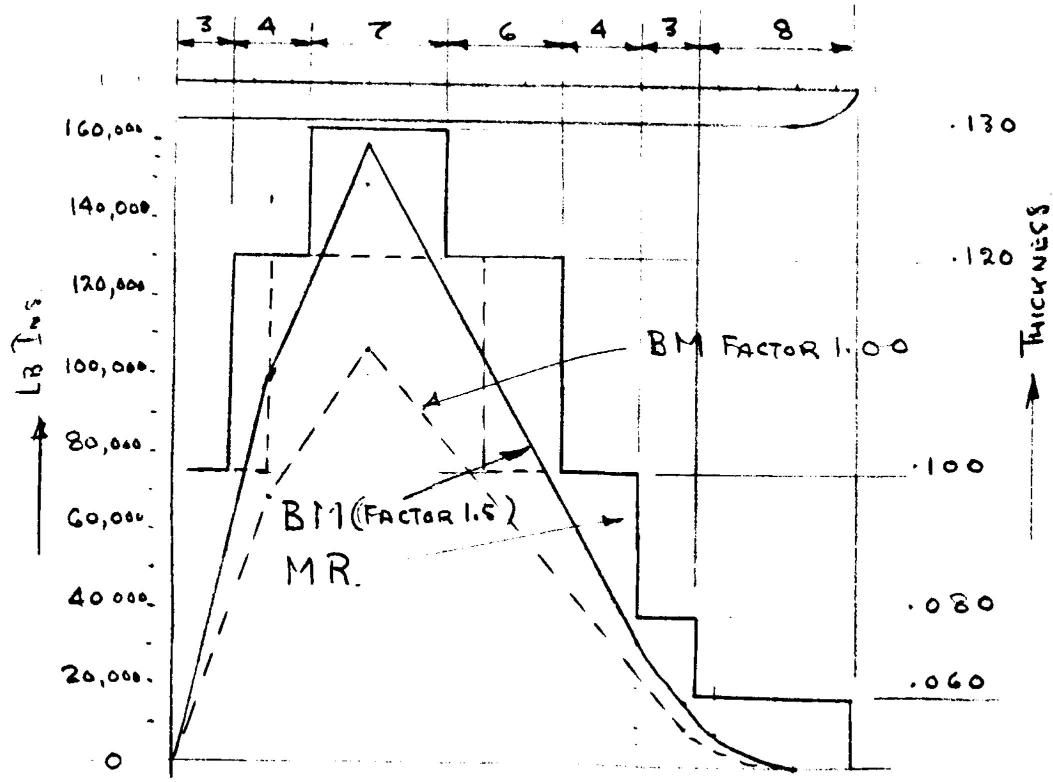
t = .120

MR = 101,000 (1.298) = 131,000 LB INS.

t = .130

MR = 118,000 (1.408) = 166,000 LB INS.

REQUIRED SKID THICKNESS



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SKID BAFFLES.

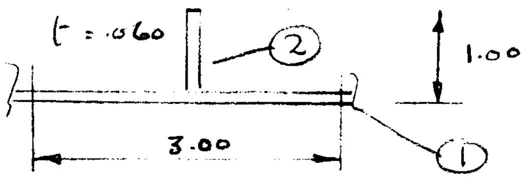
GROUND CONTACT AREA = $8 \times 5 = 40 \text{ INS}^2$.

LOAD / SQ IN = $7950/40 = 199$ LB

CAP TRANSVERSE BENDING

$$= \frac{w\ell^2}{12} = \frac{199(5)^2}{12} = 415 \text{ LB INS / IN.}$$

CONSIDER BAFFLES 1" DEEP 3" CENTERS.



ITEM	AREA	Y_{XX}	AY_{XX}	Y_{NA}	AY_{NA}^2	I_o
1	.176	.030	.0053	.120	.00254	.000054
2	.060	.500	.030	.350	.00735	.005
	.236		.0353		.00989	.005054
						.00989
						.014944

$$Y_{NA} = \frac{.0353}{.236} = .150$$

$$Z_{TEN} = \frac{.014944}{.850} = .0176$$

$$f_T = \frac{415(3)}{.0176} = 70,600 \text{ P.S.I}$$

$$MS = \frac{130,000}{70,600} - 1 = 0.84$$

FOR FACTOR OF 1.00

MS = 1.76

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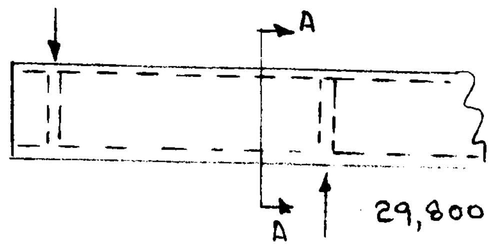
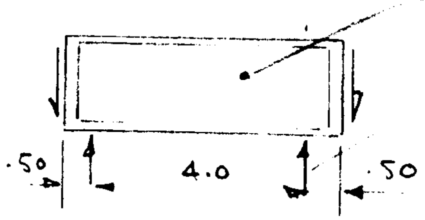
SKID BAFFLES
INBOARD END OF SKID



SECTION AA



B M ON BAFFLE

$$= \frac{33,775}{4} = 8444 \text{ LB INS.}$$

$$f_B = \frac{8444\ (6)}{.120(2)^2} = 106,000 \text{ PSI}$$

$$MS = \frac{156,000}{106,000} - 1 = 0.47$$

SHEAR

$$f_s = \frac{16,887}{(2)\ .120} = 70,500 \text{ PSI}$$

$$MS = \frac{80,000}{70,500} - 1 = 0.13$$

FOR FACTOR OF 1.00

$$MS = 0.69$$

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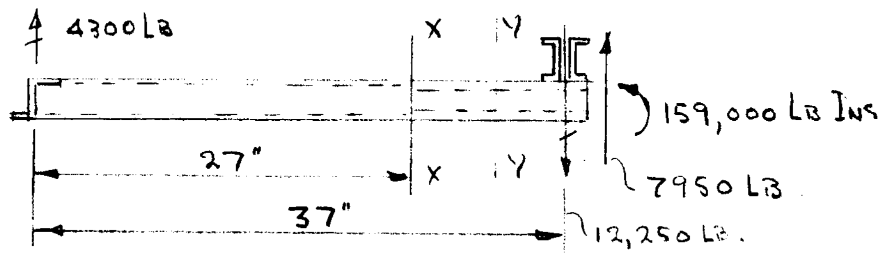
SKID HOUSING (SEE DRAWINGS FIG. 13 AND 14).

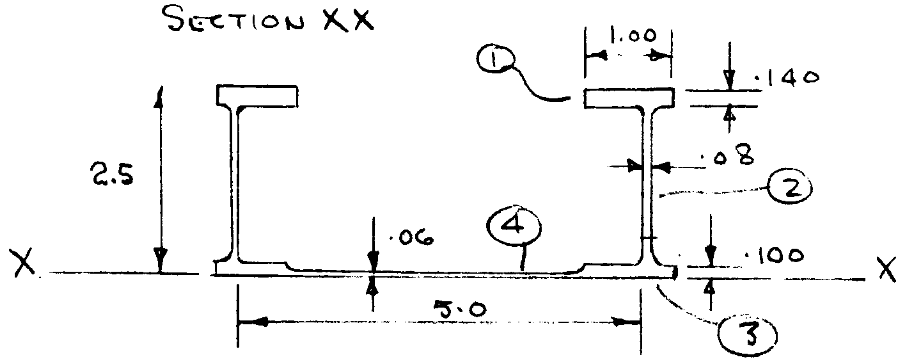


BENDING AT XX

$$M = 4300(27) = 116,000 \text{ LB INS.}$$

SECTION PROPERTIES.

SECTION XX



ITEM	AREA	Y_{XX}	$A\,Y_{XX}$	Y_{NA}	$A\,Y_{NA}^2$	I_o
1	.140	2.43	.340	1.42	.2825	.00024
2	.181	1.23	.222	.22	.0088	.077
3	.100	.05	.005	.96	.0920	.00008
4	.105	.03	.003	.98	.1007	.00003
	.566		.570		.4840	07735

$$Y_{NA} = \frac{.570}{.566} = 1.010 \qquad \begin{array}{r} .4840 \\ \hline .56135 \end{array}$$

$$f_B = \frac{116,000(1.49)}{(2)\,.56135} = 154,000 \text{ PSI}$$

$$MS = \frac{156,000}{154,000} - 1 = 0.02$$

FOR FACTOR OF 1.33 $\quad MS = 0.15$

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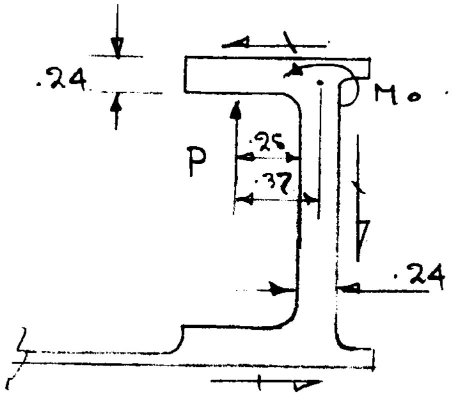
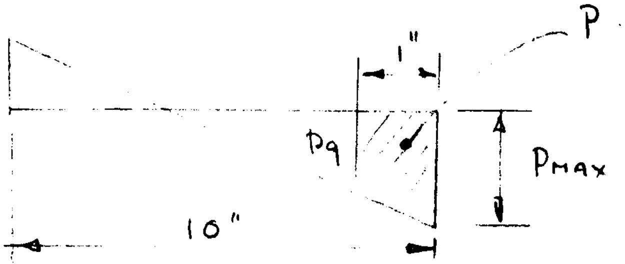
SKID HOUSING

SECTION YY FLANGE BENDING





$$P_q = \frac{29500(4)}{(2.5)(5.0)} + 795 = 10,345 \text{ LB/IN.}$$

$$P = \frac{P_{MAX} + P_q}{2} = \frac{12,695 + 10,345}{2} = 11520 \text{ LB/IN}$$

$$M_o = \frac{11,520(.37)}{2} = 2140 \text{ LB INS.}$$

$$f_B = \frac{2140(6)}{(1)(.24)^2} = 223,000 \text{ LB INS.}$$

ALLOWABLE AT 600°F WITH BENDING MODULUS
= 230,000 PSI

$$MS = \frac{230,000}{223,000} - 1 = 0.03.$$

FOR FACTOR OF 1.33 MS = 0.17.

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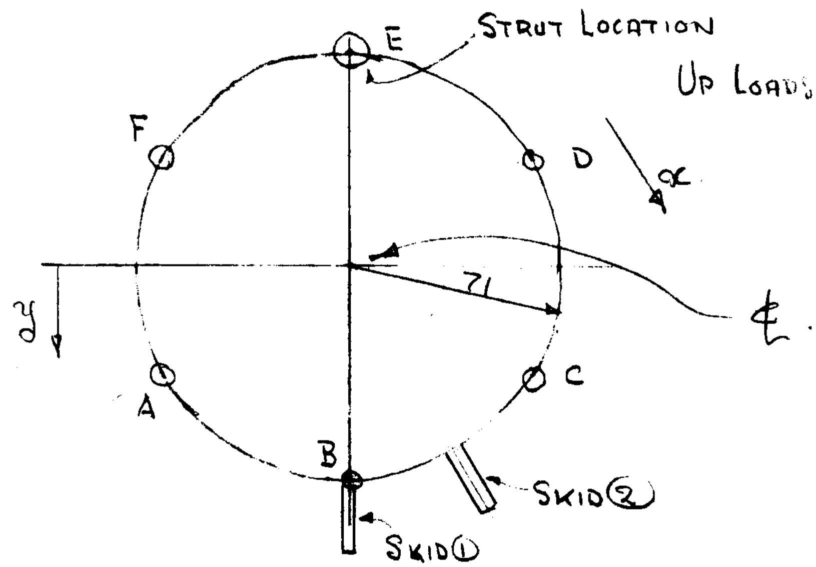
OUTER RING (71" RAD) SEE FIG. 13, 14 AND 16 FOR LOAD PATHS.
LOAD ON RING INDUCED BY SKIDS



LOAD ON RING AT SKID① = 12,250 LB

TORQUE ABOUT H/S CENTERLINE = 12,250 (71) = 869,750 LB INS.

$\Sigma y^2 = 2[71^2 + 2(35.5)^2] = 15,122$

REACTIONS A & C

$-\frac{869,750}{15122}(35.5) - \frac{12,250}{6}$

$= -2040 - 2041 = -4081$ LB.

REACTION B

$-\frac{869,750}{15,122}(71) - \frac{12,250}{6}$

$= -4080 - 2041 = -6121$ LB

REACTION D & F

$= 2040 - 2041 = -1$ LB

REACTION E

$= 4080 - 2041 = 2039$ LB.

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LOAD AT SKID (2) = 12,250 LB.

TORQUE ABOUT CENTROID = 869,750 LB. INS

$\Sigma x^2 = 4(61.5)^2 = 15,150$

REACTION A & D

$= -\frac{12250}{6} = -2041$ LB

REACTION B & C

$- \frac{869,750}{15,150}(61.5) - 2041$

$= -3540 - 2041 = -5581$ LB.

REACTIONS F & E

$= 3540 - 2041 = 1499$ LB

TOTAL REACTIONS.

A = −4081 − 2041 = −6122 LB.
B = −6121 − 5581 = −11,702 LB
C = −4081 − 5581 = −9662 LB
D = −1 − 2041 = −2042 LB
E = 2039 + 1499 = 3538 LB
F = −1 + 1499 = 1498 LB.

CONSIDER RING CUT AT A

THEN STATIC MOMENT AT B

= −3061 (61.5) = −188,000 LB INS

AT SKID (2)

= −3061 (71) + 548 (35.5)
−217,300 + 19,500 = −197,800 LB INS

AT C

= −6122 (61.5) + 548 (61.5) + 12,250 (35.5)
= −188,000 + 33,700 + 435,000
= 280,700 LB INS

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STATIC MOMENT ON RING AT 71" RAD.

AT D

$= +548(61.5) + 12{,}250(71) - 9662(61.5)$

$= 33{,}700 + 869{,}750 - 594{,}000$

$309{,}450$ LB INS

AT E

$-6122(+61.5) + 12{,}250(-35.5) - 9662(-61.5) - 2042(61.5)$

$-188{,}000 - 435{,}000 + 594{,}000 + 125{,}500$

$= +96500$ LB INS

AT F

$-6122(-61.5) + 548(-61.5) + 12{,}250(-35.5) - 2042(+61.5)$
$+ 3538(+61.5)$

$= -188{,}000 + 33{,}700 + 435{,}000 + 125{,}500 - 218{,}000$

$= -188{,}200$ LB INS.

AT A

$+548(-61.5) + 12{,}250(-71) - 9662(-61.5) + 3538(61.5)$
$+ 1498(61.5)$

$= -33{,}700 - 869{,}750 + 594{,}000 + 218{,}000 + 92{,}300$

$+ 850$ LB INS

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SHEAR ON RING AT 71" RAD.

$A = \pm 3061$

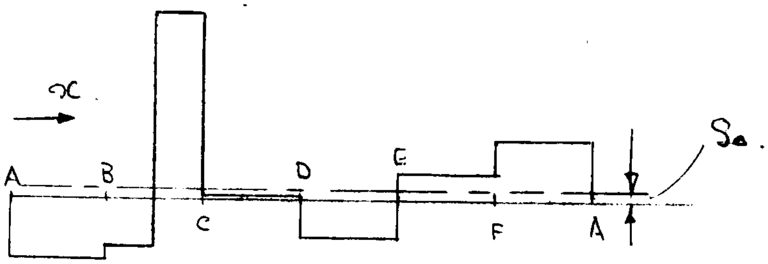
$B = -3061 - 11,702 + 12,250 = -2513$

$(2) = -2513 + 12,250 = +9737$

$C = +9737 - 9662 = +75$

$D = +75 - 2042 = -1967$

$E = -1967 + 3538 = +1571$



$$\int S\,dx = -3061x - 1256x + 4868x + 75x - 1967x + 1571x + 3061x$$
$$= 3291x$$

$$S_o = \int S\,dx / x = 558\text{ LB.}$$

MOMENT DUE TO REDUNDANT SHEAR (m_o).

AT

A & D = 0

B, C, E & F $= -558(\pm 61.5) = \pm 34,400$ LB INS.

AT SKID (2) $= -558(71) = -39,600$ LB INS.

$$\int m_o\,dx = +39,600(1.5)x - 39600(2x)$$

0

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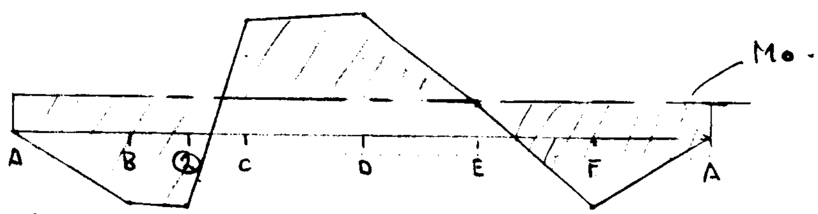
REDUNDANT MOMENT (RING AT 71" RAD.)



$$\int M_s\,dx + \int M_o\,dx + \int m_o\,dx = 0$$

$$\int M_s\,dx = -94{,}000x - 99{,}000x + 25000x + 290{,}000x + 200{,}000x + 142{,}000x + 94{,}000x$$
$$= 558{,}000x.$$

THEN $M_o = 430{,}000 / 6 = 71{,}600$ LB INS

TOTAL MOMENT

A	=	−71,600	− 0	− 0	= −71,600 LB INS
B	=	−71,600	− 188,000	− 34,400	= −294,000
C	=	−71,600	+ 280,700	− 34,400	= +174,700
D	=	−71,600	+ 309,450	− 0	= +237,850
E	=	−71,600	+ 96,500	+ 34,400	= +59,300
F	=	−71,600	+ 188,200	+ 34,400	= +151,000
②	=	−71,600	− 197,800	− 39,600	= −309,000

TORQUE ON RING

ASSUME SKID HOUSINGS REACT TORQUE

THEN MAX TORQUE = 12,250 (9.50)
= 116,400 LB INS . ON RING.

END LOAD ON HOUSING

$$= \frac{116{,}400}{2.25} = 51{,}800 \text{ LB.}$$

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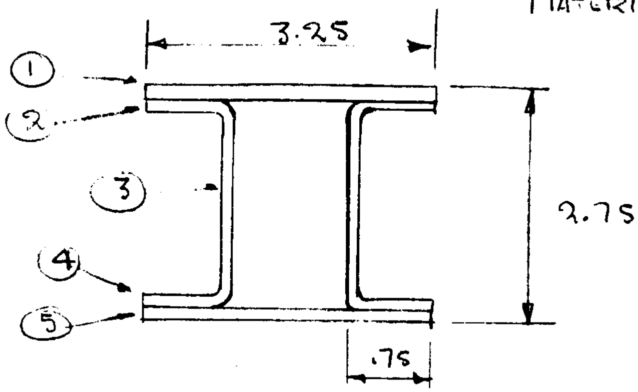
RING AT 71" RADIUS

SECTION PROPERTIES.

MATERIAL .156 THICK.



ITEM	AREA	Y_{NA}	$A Y_{NA}^2$	I_o
1	.506	1.297	.853	.00103
2	.234	1.141	.305	.00057
3	.664	0		.251
4	.234	1.141	.305	.00057
5	.506	1.297	.853	.00103
	2.144		2.316	.25420

$$\begin{array}{r} .25420 \\ 2.316 \\ \hline 2.5702 \end{array}$$

STRESS IN RING DUE TO BENDING

$$f_b = \frac{309,000\,(1.297)}{2.56814} = 156,000 \text{ PSI.}$$

ALLOWABLE AT 600°F - 156,000 P.S.I

MS = ZERO

FOR FACTOR OF 1.33 MS = 0.13.

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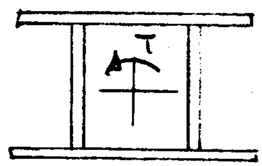
RING AT 71" RAD.

SHEAR STRESS.

$T = 116,400$ LB INS.



$$q = \frac{T}{2A} = \frac{116,400}{2(1.75)(2.75)} = 12,100 \text{ LB/IN}$$

$$f_s = \frac{12,100}{.156} = 77,500 \text{ PSI}$$

DIRECT SHEAR = 9737 LB

$$q = \frac{VQ}{I} = \frac{9737(1.10)}{2.5702} = 4160 \text{ LB/IN.}$$

$$f_s = 4160/2(.156) = 13,350 \text{ PSI.}$$

TOTAL STRESS = 77,500 + 13,350 = 90,850 PSI

ALLOWABLE AT 600°F = 105,000 PSI

$$MS = \frac{105,000}{90,850} - 1 = 0.15$$

MS FOR FACTOR OF 1.33 = 0.30

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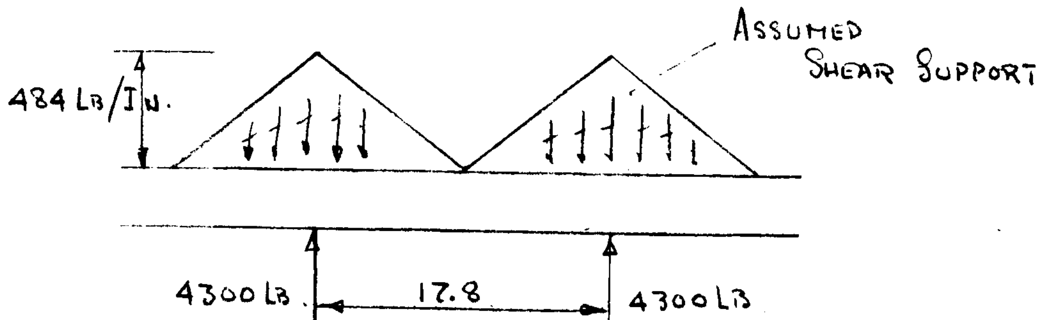
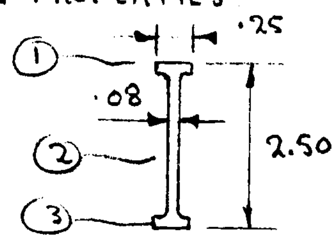
INNER RING (34" RAD.)



MAX SUPPORTING SHEAR $= \dfrac{4300}{17.8(.5)} = 484$ LB/IN.

RING BENDING $= \dfrac{Wl}{6} = \dfrac{4300\,(17.8)}{6} = 12{,}750$ LB INS.

SECTION PROPERTIES



ITEM	AREA	Y_{NA}	$A\,Y_{NA}^2$	I_o
1	.0136	1.21	.0199	.00007
2	.2000	0	0	.1040
3	.0136	1.21	.0199	.00007
	.2272		.0398	.10414

$$\begin{array}{r} .10414 \\ .0398 \\ \hline .14394 \end{array}$$

$$f_B = \frac{12{,}750\,(1.25)}{.14394} = 111{,}000 \text{ PSI}$$

$$M.S. = \frac{156{,}000}{111{,}000} - 1 = 0.40.$$

FOR FACTOR OF 1.33 M.S = 0.59.

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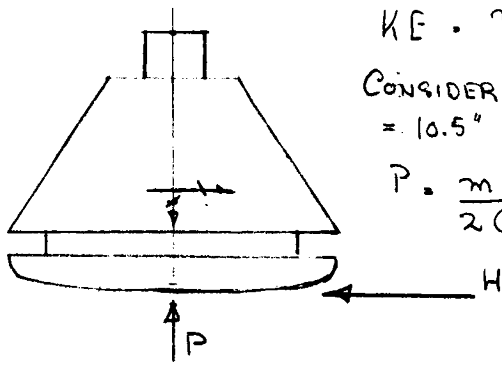
GROUND IMPACT CONDITION (VERTICAL)



$KE = \frac{mV^2}{2g}$

CONSIDER STRUT TRAVEL $= 10.5'' = 0.88$ FEET

$P = \frac{mV^2}{2(.88)}$

IMPACT LOAD

$P = \frac{mV^2}{2gS} = \frac{10{,}600\,(15)^2\,(1.33)}{(2)\,32.2\,(.88)} = 55{,}500$ LB ULT.

$H = .35V = .35(55{,}500) = 19{,}400$ LB. To O.

ASSUME GROUND CONTACT = 34" RAD

AREA $= \pi(34)^2 = 3640$ INS^2

PRESSURE ON AFT H/S $= 55{,}500/3640 = 15.25$ P.S.I

MIN SKIN THICKNESS = .010

HOOP STRESS IN SKIN $= \frac{PR}{2t} = \frac{15.25\,(175)}{(2)(2)(.010)}$ *

$= 66{,}800$ P.S.I.

CORE SHEAR AT 34" RAD

$= \frac{55{,}500}{34(2)\pi(2)} = 130$ P.S.I.

CORE SHEAR AT 71" RAD

$= \frac{55{,}500}{71(2)(\pi)(2)} = 62.25$ P.S.I

* CENTER PANEL OF AFT HEAT SHIELD CONSIDERED ACTING AS A DIAPHRAGM IN HOOP COMPRESSION.

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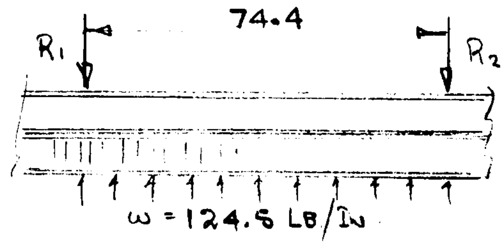
GROUND IMPACT CONDITION. (VERTICAL)

BENDING ON RING AT 71" RAD.



$R_1 = R_2 = 74.4(124.5) = 9250$ LB.

$M = \frac{1}{12} w \ell^2 = \frac{124.5\,(74.4)^2}{12} = 57{,}200$ LB INS.

$f = \frac{57{,}200\,(1.297)}{2.56814} = 28{,}900$ P.S.I

HIGH MARGIN.

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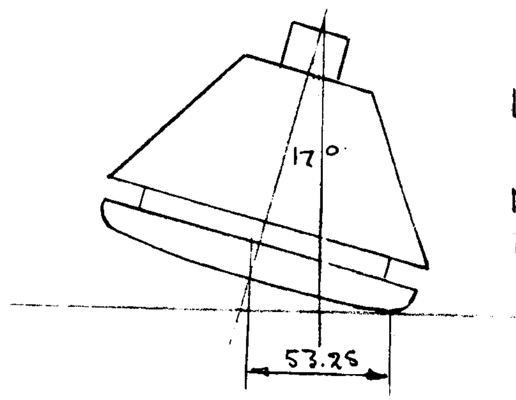
GROUND IMPACT CONDITION (17°).



LOAD = 55,500 LB ULT. (REF PAGE 2.1)

NOTE IMPACT POINT IS ON THE AFT HEAT SHIELD.

LINE LOAD ON RING AT 71"

$$\text{MEAN} = \frac{55,500}{71(2)\pi} = 124.5 \text{ LB/IN}$$

$$\text{MAX} = 124.5\left(\frac{71+53.25}{71}\right) = 218 \text{ LB/IN.}$$

$$\text{MIN} = 124.5\left(\frac{71-53.25}{71}\right) = 31 \text{ LB/IN}$$

RATE OF CHANGE IN LOAD / DEGREE

$$= \frac{218-31}{180} = 1.04 \text{ LB/IN.}$$

CHANGE OF LOAD BETWEEN SHOCK STRUTS

$$= \frac{218-31}{180}(60) = 62.33 \text{ LB.}$$

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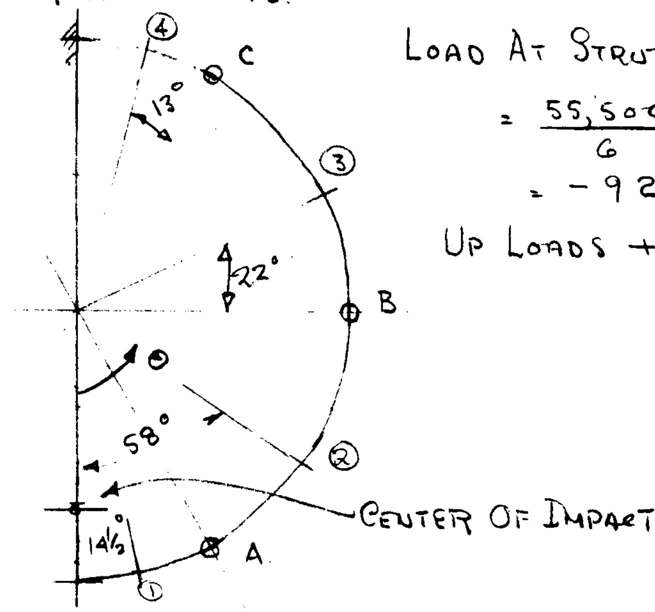
GROUND IMPACT CONDITION (12°)

RING AT 21" RAD.



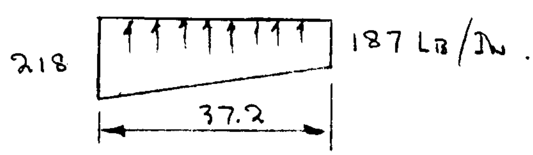
LOAD AT STRUTS A, B, AND C

$$= \frac{55,500}{6}$$

$$= -9250 \text{ LB}$$

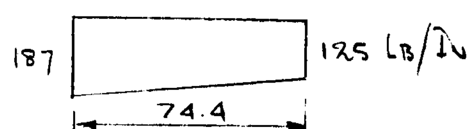
UP LOADS + VE.

LOAD ON BAY ①



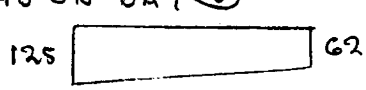
= 7520 LB.

LOAD ON BAY ②



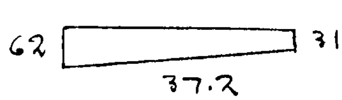
= 11,580 LB.

LOAD ON BAY ③



= 6930 LB.

LOAD ON BAY ④



= 1720 LB.

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GROUND IMPACT CONDITION (17°)

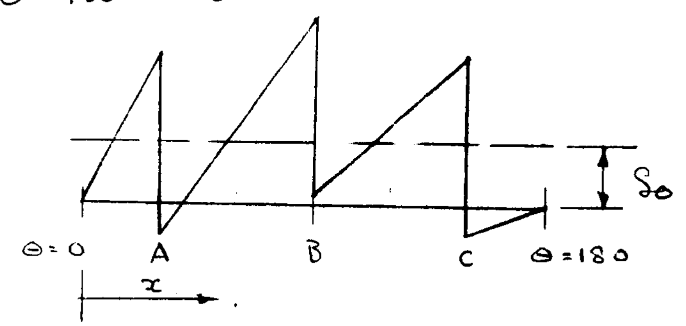
SHEAR ON RING AT 71" RAD

A = 7520 AND -1730

B = 9580 AND 600

C = 7530 AND -1720

Θ = 180° = 0



$$\int S\,\partial x = 3760(.5x) + 3925(x) + 4065(x) - 860(.5x)$$
$$= 9440x.$$

$$S_0 = \int S\,\partial x / x = 3146 \text{ LB}$$

MOMENT DUE TO REDUNDANT SHEAR (m_s)

AT A = −3146(35.5) = −111,200 LB INS.

AT B = −3146(71) = −222,400 LB INS.

AT C = −3146(35.5) = −111,200 LB INS.

AT Θ = 180 = 0.

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GROUND IMPACT CONDITION (17°)

STATIC MOMENT ON RING AT 71" RAD.

AT A

$= 7520(.267)71 = 142,800$ LB INS

AT B

$= 7520(.968)71 - 9250(61.5) + 11,580(.5299)71$

$= 518,000 - 568,900 + 436,000$

$= 385,100$ LB INS

AT C

$= 7520(.709)71 - 568,900 + 11,580(.999)71 - 568,900 + 6930(.616)71$

$= 378,500 - 568,900 + 820,000 - 568,900 + 303,000$

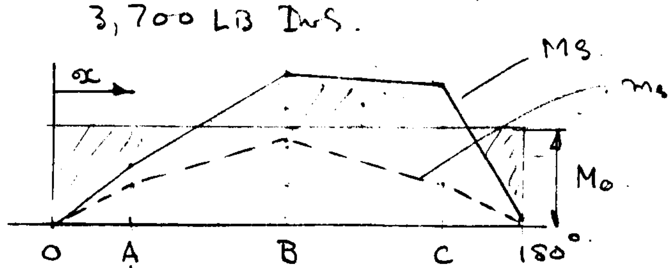
$= +363,700$ LB INS

AT $\theta = 180°$

$7520(.242)71 - 9250(35.5) + 11,580(.848)71 - 9250(71) + 6930(.927)71 - 9250(35.5) + 1720(20.2)$

$= 129,100 - 328,000 + 695,000 - 656,000 + 456,000 - 328,000 + 35,600$

$= 3,700$ LB INS.



$\int Ms\,dx = 71,400(.5x) + 263,950(x) + 374,400(x) + 183,700(.5x)$

$= 765,900\,x.$

$\int ms\,dx = -55,600(.5x) - 166,800(x) - 166,800(x) - 55,600(.5x)$

$= -389,200\,x.$

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GROUND IMPACT CONDITION (17°)

$$\int M_s \, dx + \int m_s \, dx + \int m_o \, dx = 0.$$

$$m_o = \int M_s \, dx + \int M \, S_o \, dx \Big/ x$$

$$= 765{,}900x - 389{,}200x \Big/ 3x.$$

$$= 125{,}500 \text{ LB INS.}$$

TOTAL MOMENT ON RING AT 71" RAD.

LOCATION	M_s	M_{S_o}	M_o	TOTAL
$\theta = 0$	0	0	−125,500	−125,500
$\theta = 30°$ A	142,800	−111,200	−125,500	−93,900
$\theta = 90°$ B	385,100	−222,400	−125,500	+37,200
$\theta = 150°$ C.	363,700	−111 200	−125,500	+127,000.
$\theta = 180$	3,700	0	−125 500	−121 800

STRESS DUE TO BENDING.

$$f_B = \frac{127{,}000\,(1.297)}{2.56814} = 64{,}000 \text{ PSI}$$

STRESS FOR REVISED ULTIMATE LOAD OF 106,000 LB. THIS LOAD IS BASED ON A RESULTANT VERTICAL IMPACT VELOCITY OF 22 FT PER SECOND FOR GROUND SLOPING UPWARDS TO THE DIRECTION OF TRAVEL

$$f_R = \frac{64{,}000\,(106{,}000)}{55{,}500} = 123{,}000 \text{ PSI}$$

$$MS = \frac{156{,}000}{123{,}000} - 1 = 0.27$$

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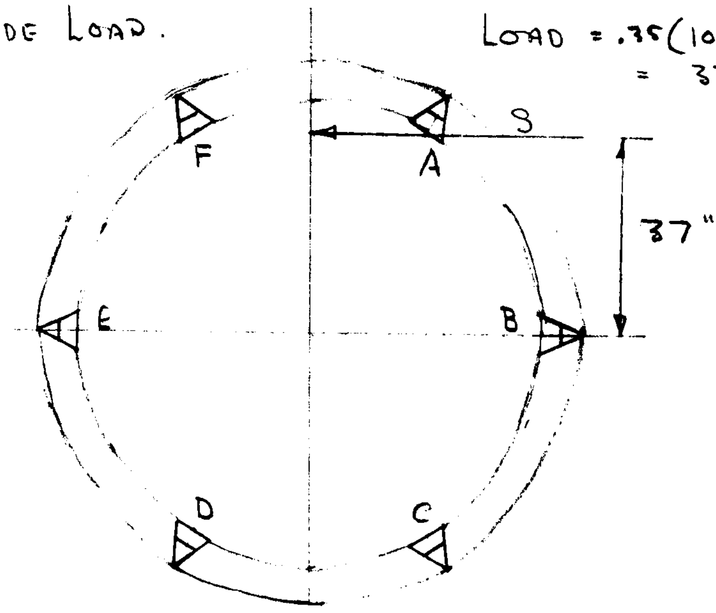
GROUND IMPACT CONDITION 17° (WITH 12° YAW)

SIDE LOAD.

LOAD = .35(106,000)
= 37,200 LB.



TORQUE = 37 (37,200) = $1.380(10)^6$ LB INS

SIDE LOAD / LINK = $\frac{1.380(10)^6}{71\ (6)}$ = 3240 LB.

DIRECT LOAD / LINK = $\frac{37,200}{6}$ = 6200 LB.

LOAD AT A AND F
= 6200(.866) + 3240
= 5370 + 3240 = 8610 LB.

LOAD AT E AND B.
= 0 + 3240 = 3240 LB

LOAD AT C AND D.
= 5370 − 3240 = 2130 LB.

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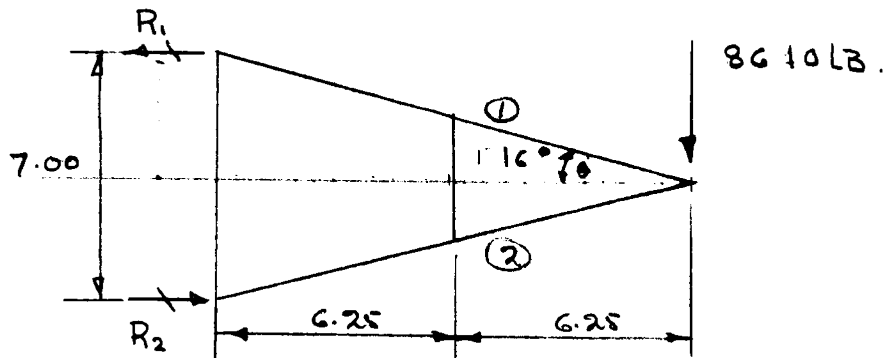
GROUND IMPACT CONDITION 17°

SIDE LOAD LINKS.

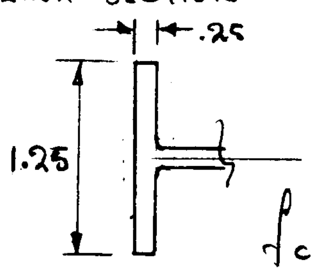


$R_1 = R_2 = 8610\,(12.5)/7 = 15350$ LB.

LOADS IN LINK 1 & 2

$= \dfrac{R}{\cos\theta} = \dfrac{15350}{.961} = 16{,}000$ LB

LINK SECTION



$A = .312 \quad I = .0408 \quad \rho = .362$

$\dfrac{\ell}{\rho} = 6.25/.362 = 17.2$

$f_c = \dfrac{16{,}000}{.312} = 51{,}300$

MATERIAL 7075-T6

COMPRESSIVE ALLOWABLE = 56,000 PSI (AT 200°F.)

$MS = \dfrac{56{,}000}{51{,}300} - 1$

$= 0.09.$

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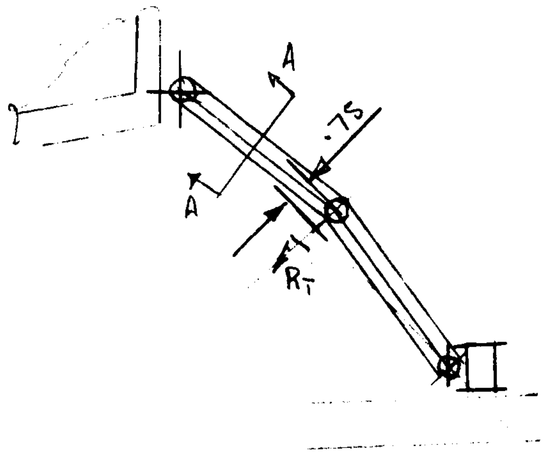
TORQUE ON SIDE LOAD LINKS

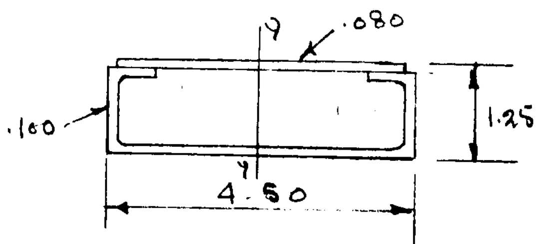


$R_T = \frac{16{,}000\ (.75)}{6.25} = 1920\ LB$

TORQUE $= 1920(3.5) = 6720\ LB\ INS.$

SECTION A A

$I_{yy} = 2.638$



$q = \frac{T}{2A} = \frac{6720}{2(4.5)(1.25)} = 597\ LB/IN.$

$f_s = \frac{597}{.08} = 7500\ PSI.$

$M = 8610\ (7.3) = 62{,}800\ LB\ INS$

$f_B = \frac{62{,}800\ (2.25)}{2.638} = 53{,}600\ PSI$

$MS = \frac{60{,}000}{53{,}600} - 1 = 0.12$

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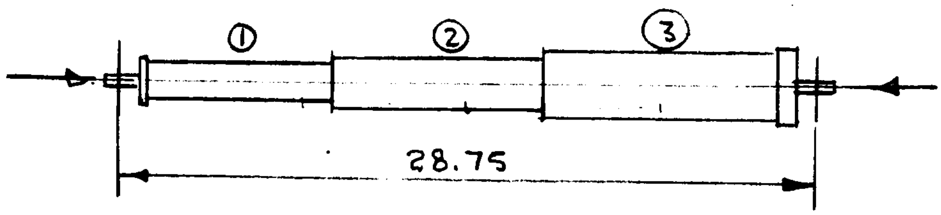
SHOCK STRUT (REF PAGE 65 REPORT SID 66-106)

LOAD = 23,264 (1.33) = 31,000 LB (ULT)



ITEM	THICKNESS	DIAM	AREA	I	ρ	LENGTH
①	0.080	1.50	.357	.0897	.502	9.5
②	0.060	2.00	.365	.1725	.687	8.4
③	0.060	2.50	.459	.3460	.870	10.8

$$\frac{\ell}{\rho} = \frac{9.5}{.502} + \frac{8.4}{.687} + \frac{10.8}{.870} = 43.5$$

TYPICAL STAINLESS STEEL ALLOWABLES AT 600F

COLUMN ALLOWABLE = 96,000 P.S.I.

$$f_c = \frac{31,000}{.357} = 87,000 \text{ P.S.I}$$

$$MS = \frac{96,000}{87,000} - 1 = 0.10$$

WORKING PRESSURE

PISTON AREA = $1.19^2\pi$ = 4.45 INS^2

PRESSURE = 31,000 / 4.45 = 7000 PSI (ULT)

STRESS IN WALL OF ITEM ①

$$f_T = \frac{PR}{t} = \frac{7000\,(1.19)}{.06} = 139,000 \text{ PSI}$$

$$MS = \frac{156,000}{139,000} - 1 = 0.12$$

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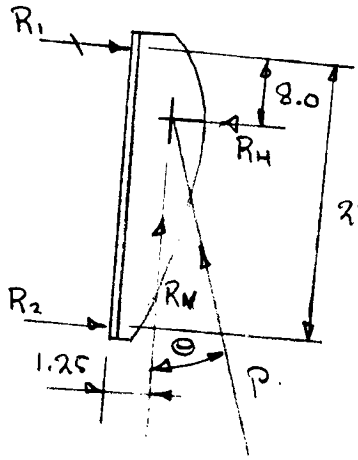
SIDEWALL FITTING - SHOCK STRUT TO INNER STRUCTURE ATTACHMENT.



$\Theta = 28°$

$\sin\Theta = .46947$

$\cos\Theta = .88295$

$P = 23,264(1.33)$
$= 31,000$ LB.

$R_H = .46947(31,000) = 14,550$ LB.

$R_V = .88295(31,000) = 27,300$ LB

$$R_2 = \frac{8(14,550) - 1.25(27,300)}{28.25} = 2910 \text{ LB}$$

$R_1 = 14,550 - 2910 = 11,640$ LB.

LOAD ON BOND (FITTING TO SIDEWALL)

$$q = \frac{27,300}{29} = 945 \text{ LB/IN (AVERAGE)}$$

ASSUME TRIANGULAR DISTRIBUTION.

$q_{MAX} = (2)945 = 1890$ LB/IN

BASE OF FITTING 2.50 WIDE

$$\text{BOND STRESS} = \frac{1890}{2.50} = 759 \text{ P.S.I}$$

$$MS = \frac{1320}{759} - 1 = 0.74.$$

BOND ALLOWABLE AT 200°F = 1320 P.S.I.

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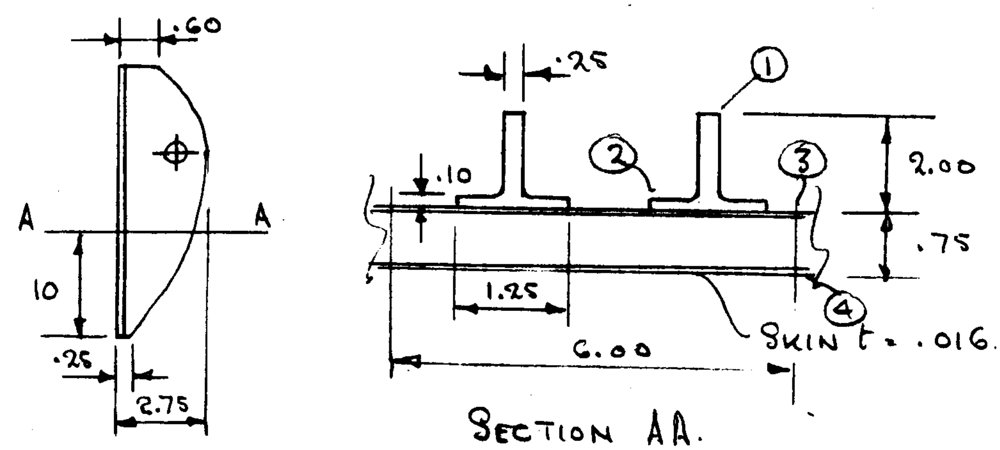
SIDEWALL FITTING - SECTION PROPERTIES



SECTION AA.

ITEM	AREA	y_{xx}	Ay_{xx}	y_{NA}	Ay_{NA}^2	I_o
1	.950	1.800	1.715	.375	.1335	.286
2	.250	.800	.200	.625	.0978	.0002
3	.096	.750	.072	.675	.0436	
4	.096	.000	.000	1.425	.1960	
	1.392		1.987		.4709	.2862

$$Y_{NA} = \frac{1.987}{1.392} = 1.425$$

$$\begin{array}{r} .2862 \\ .4709 \\ \hline .7571 \end{array}$$

$M = (10)\,2910 = 29,100$ LB INS.

END LOAD $= \frac{1890\,(5)}{2} = 4730$ LB (TENSION)

$$f_T = \frac{29,100\,(1.425)}{.7571} + \frac{4730}{1.392}$$

$$= 54,900 + 3400 = 58,300 \text{ PSI}$$

INNER SKIN ALLOWABLE = 60,000 PSI.

$$MS = \frac{60,000}{58,300} - 1 = 0.03.$$

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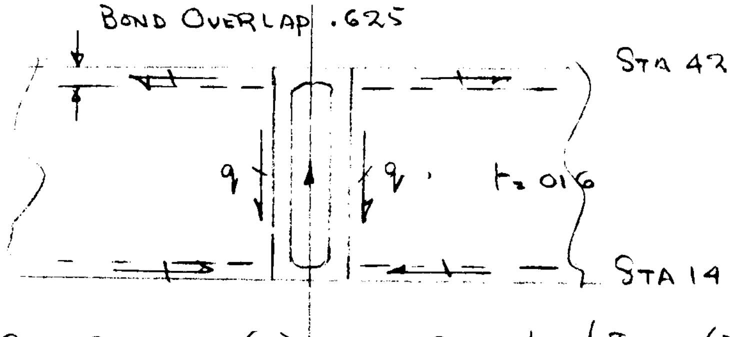
SIDEWALL SKIN (COMMAND MODULE INNER STRUCTURE AFT SIDEWALL)



$$q = \frac{27,300\ (2)}{29\ (2)} = 945 \text{ LB/IN. (IN BOTH SKINS)}$$

$$f_s = \frac{945}{.032} = 29,500 \text{ P.S.I}$$

$$MS = \frac{38,000}{29,500} - 1 = 0.29$$

BOND STRESS AT STA 42.

$$f_B = \frac{945}{(2)(.625)} = 755 \text{ P.S.I.}$$

BOND ALLOWABLE AT 200°F = 1320 P.S.I

$$MS = \frac{1320}{755} - 1 = 0.75$$

SHEAR ALLOWABLE OF HONEYCOMB PANEL = 38,000 P.S.I.

RADIAL LOADS ARE RESISTED BY THREADED ATTACHMENTS IN THE RING STA. 14 AND 42.

THERE ARE NO OTHER PROBLEMS ASSOCIATED WITH THE COMMAND MODULE INNER STRUCTURE

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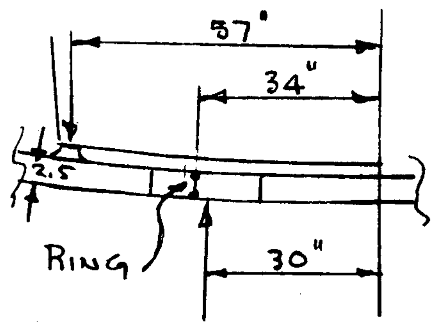
WATER IMPACT CONDITION.

135 P.S.I ON 630 INS^2 · (REF PAGE 2.1 OF SIX LEG STUDY)



NOTE:– FOR THIS CONDITION THE H/S IS CONSIDERED IN THE CLOSED POSITION WHICH IS MORE CONSERVATIVE.
WITH THE H/S DEPLOYED THE LOAD WOULD BE ABSORBED BY THE SHOCK ABSORBERS.

LINE LOAD AT 57" RAD. INNER STRUCTURE SUPPORT

MEAN LOAD $= \dfrac{135(630)}{\pi(114)} = 237$ LB/IN.

MAX LOAD $= \dfrac{237(87)}{57} = 362$ LB/IN

MIN LOAD $= \dfrac{237(27)}{57} = 112$ LB/IN.

MAX BENDING ON CENTER PANEL

$= 237(50) = 11850$ LB INS

SKIN THICKNESS = .018 (MAX)

$f_B = \dfrac{11{,}850}{2.5(.036)(2)} = 132{,}000$ P.S.I / INCH WIDTH

$M\,S = \dfrac{140{,}000}{132{,}000} - 1 = 0.06.$

+Z QUADRANT $t = .008$ (MIN)

$M = 112(42) = 4700$

$f_B = \dfrac{4700}{2.5(.008)(2)} = 117{,}500$ P.S.I

$M\,S = \dfrac{120{,}000}{117{,}500} - 1 = 0.02$

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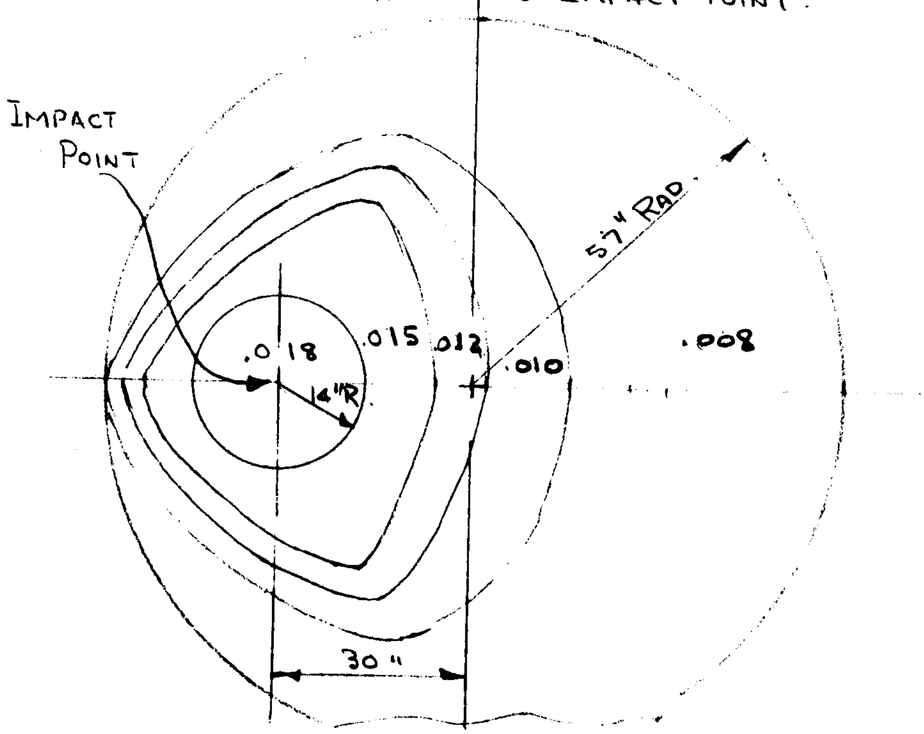
WATER IMPACT CONDITION.
H/S SKIN THICKNESS.

THICKNESS	ALLOWABLE STRESS	MOMENT OF RESISTANCE
.008	120,000 PSI	4800 LB INS.
.010	125,000	6250
.012	130,000	7800
.015	135,000	10,100
.017	135,000	11,400
.018	135,000	12,200

SCALE 1:24.
SKIN PROFILE RELATIVE TO IMPACT POINT.



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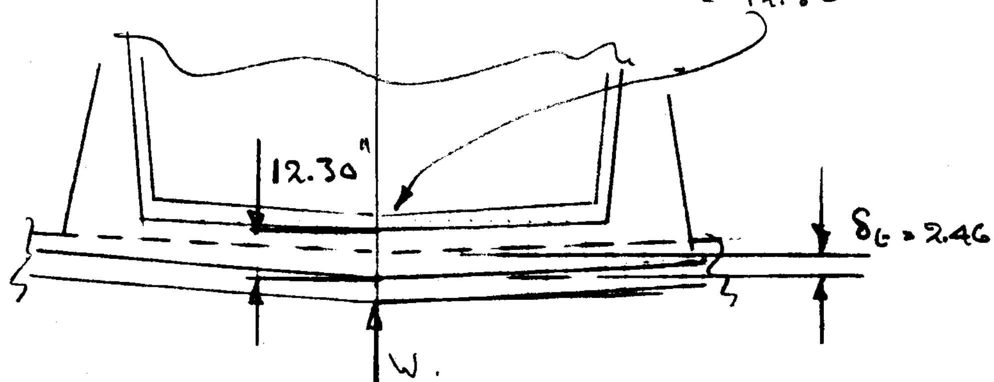
DEFLECTIONS.

VERTICAL GROUND CONTACT CONDITION.

GAP BETWEEN H/S AND INNER STRUCTURE = 0.30

H/S IS DEPLOYED 12.00 TOTAL GAP = 12.00 + 0.30

= 12.30"



$$W = \frac{10{,}600\,(15)^2\,(12)}{2\,(32.2\,(4))} = 111{,}000 \text{ LB}$$

DEFLECTION OF H/S CENTER $\delta_c = \dfrac{96\,W\,R^2}{144\pi E t^3}$

$$= \frac{96\,(111{,}000)\,(34)^2}{144\,(\pi)(25)(10)^6(.374)} = 2.900 \text{ INCHES.}$$

DEFLECTION OF HOUSING $= \dfrac{W l^3}{48\,EI} = \delta_H$

$$\delta_H = \frac{111{,}000\,(37)^3}{12\,(48)(25)(10)^6(1.1967)} = .327 \text{ INCHES}$$

STRUT STROKE (δ_S) = 4 INCHES

$\delta_T = \delta_C + \delta_H + \delta_S$.

$\delta_T = 4.00 + 2.90 + .327 = 7.227$ INCHES.

WATER IMPACT

$$\delta_T = \frac{(\delta_C + \delta_H)\,10{,}600\,(8)}{111{,}000} = 2.46 \text{ INCHES}$$

IN THE OPEN POSITION THE DEFLECTED H/S DOES NOT CONTACT THE INNER STRUCTURE.

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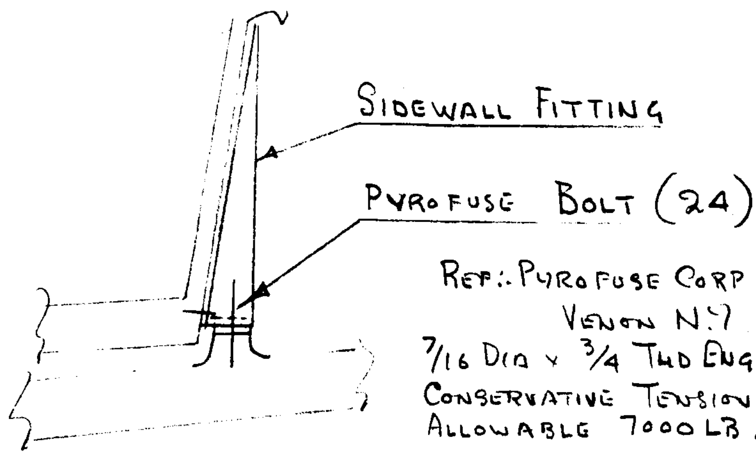
ATTACHMENT OF AFT HEAT SHIELD TO INNER STRUCTURE



REF: PYROFUSE CORP
VENON N.Y.
7/16 DIA × 3/4 THD ENGAGEMENT
CONSERVATIVE TENSION
ALLOWABLE 7000 LB.

BOLT IS LOADED BY CONDITIONS WHICH INDUCE TENSION BETWEEN THE AFT H/S AND THE INNER STRUCTURE.

STAGING TRANSIENT

3.0 g LIMIT LOAD

LOAD = 3.0 (1.5) (1600) = 7200 LB ULT.

LOAD PER BOLT = 7200/24 = 300 LB.

SEA HOISTING CONDITION

31,000 (1.5) = 46,500 LB ULT.

LOAD PER BOLT = 46500/24 = 1935 LB.

MS HIGH.

ABORT INITIATION

PRESSURE ON AFT H/S = 5.7 PSI

LOAD = 5.7 (129) (144) = 106,000 LB (LIMIT)

106,000 (1.33) = 140,000 LB (ULT)

LOAD / BOLT = 140,000 / 24 = 5860 LB.

ALLOWABLE TENSION 7/16 BOLT = 7000 LB $MS = \frac{7000}{5860} - 1 = 0.20$.

APPENDIX B

TECHNICAL INFORMATION CORRESPONDENCE

This appendix includes a reply from Cleveland Pneumatic Tool Company to a NAA request for technical information based on a review of Drawing 5260-14.

THE CLEVELAND PNEUMATIC TOOL COMPANY

1301 E. EL SEGUNDO BOULEVARD • EL SEGUNDO, CALIFORNIA • PHONE: (213) SPRING 2-1361

February 11, 1966

LA 4-788

Mr. R. W. Vogler ,Mail Station GA80
North American Aviation, Inc.
Space & Information Division
12214 Lakewood Blvd.
Downey, California

Subject: NAA Request for Technical Information

Reference: NAA Letter M6A2-E-4-5034
NAA Drawing No. 5260-14

Gentlemen:

Drawing No. 5260-14, has been reviewed. The following comments are offered relative to feasibility, weight and delivery.

a) The method of stowing the struts fully-compressed and uncharged is good.

b) The six leg system is good. The performance of the assembly for one leg landing, and for six leg landing will vary significantly. An analysis of this requires a computer study.

c) The two telescoping pistons will result in a step in the load-stroke curve when the second piston is picked up during the stroke. We suggest that an orifice might be added to the piston head of the larger piston. Then, the small piston would displace oil through this orifice, while both pistons would displace oil through the orifice provided in the line. This arrangement would increase the overall efficiency.

d) The overall efficiency of a constant orifice shock absorber does not equal that of a metered orifice. As a general rule, the efficiency of a constant orifice shock absorber will be about 60 percent.

A SUBSIDIARY OF PNEUMO DYNAMICS CORPORATION

Pg. 2

NAA - S&ID 2/11/66

e) Rough calculations indicate that the construction shown may be unstable as a column. We suggest that a careful analysis be made to investigate this problem.

f) Without delving into the stress problem noted under (e), any weight estimate is of little value. Therefore, we refrain from making any estimate of the weight.

g) A ship set of shock absorber units could be designed, manufactured and drop tested in about 12 months after award of contract.

If any additional information is required, your inquiry will receive my immediate attention.

Very truly yours,
THE CLEVELAND PNEUMATIC TOOL CO.

H. G. Wesp

HGW/lh
Hugo G. Wesp

cc: W. A. Lavery
Ben Nye

APPENDIX C

MATERIALS EVALUATION

The materials requirements for the MISDAS application are derived from the AES mission and the operational and loading requirements of the landing impact attenuation system. The structural components that form part of the aft heat shield (landing legs, skids, skid housings, and associated fittings) were designed for a temperature range of -150 F to +600 F. These values, which represent the extreme temperatures at the ablator/heat shield interface, are somewhat conservative for structural design. Structural components attached to the inner capsule are designed for its anticipated temperature range of -150 F to +200 F. In general, the materials used for similar applications to Apollo are satisfactory for the MISDAS system, and no material development programs are required for the structural members.

The parameters of major importance with respect to materials selection for a land landing system are strength (F_{tu}, F_{ty}), density (ρ), toughness (notch strength, impact resistance), rigidity, producibility, and corrosion resistance. The high-strength aluminum alloys, corrosion resistant steels, and titanium alloys all possess these characteristics to the degrees shown in the data presented in Table 9.

The structural members of the heat shield, landing legs, skids, skid housings and associated supports and the shock struts could be fabricated of a high-strength corrosion-resistant steel, such as the PH 14-8 Mo material used for the Apollo heat shield. This alloy is readily weldable and affords a desirable combination of strength, toughness, rigidity, and corrosion resistance. The use of PH 14-8 Mo or equivalent high temperature metallic heat shield structure provides thermal protection in case of a premature failure of the ablator. The corrosion-resistant steels are favored for these parts over the high-strength titanium alloys because of superior fabrication and welding characteristics and greater ductility and toughness.

A superalloy such as Inconel 718 may be used for the skid thruster of the radially extended skid system. This material provides a significant combination of high-impact resistance, notch toughness and strength at cryogenic, ambient, and elevated temperatures. It readily welded and brazed to it self and to other materials such as the type 18-8 stainless steels (304L, 321, 347, etc.).

The fasteners and threaded members, should be fabricated from corrosion resistant steels of high strength toughness and corrosion resistance at the range of temperatures previously noted. An alloy that meets these requirements is A-286, the standard material used for Apollo fasteners.

The thin-walled bellows around the rocket nozzles and shock struts may be subjected to high temperatures and corrosive gases from the retrorockets. These members must be very flexible, thin walled, weldable items. Depending on actual temperature requirements, stainless steels, such as Types 304L, 321 and 347, or superalloys, such as Inconel 718 can be utilized.

Aluminum alloys, such as those used in Apollo bracketry, reinforcements, and attachments to the inner structure are considered satisfactory for similar applications with the MISDAS installation.

The requirements for heat shield ablator and ablative edge members at the interfaces between leg segments and fixed heat shield are identical to the Apollo and AES heat shield criteria. The ablator must provide thermal protection; joints must be sealed against aerodynamic entry heating; and moveable legs must be extendable after entry. The AVCOAT 5026-39 basic ablator and the silicone-based joint compound (Reference 6) developed for Apollo are applicable to the MISDAS installation.

Item	NAA-Apollo Temperature Limitation	ρ (lb/in. ^{2})	Room Temperature Properties						300 F Prop		
			F_{ty} (ksi)	F_{ty} (ksi)	F_{ty}/ρ (10^3)	e (%)	Impact (Charpy v)	E_c (10^6)	F_{ty} (ksi)	F_{ty} (ksi)	F_{t} (1
Stainless Steels											
PH 15-7 Mo (RH 1050)	-150 F	0.277	190*	175*	686	2*	4	30.0*	175*	158*	6
PH 14-8 Mo (BCHT 1050)	-300 F	0.277	185**	175**	668	11**	6.5	29.0**	172**	158**	6
A-286	-423 F	0.286	140*	95*	490	26*	56	29.0*	131*	90*	4
Aluminum Alloys											
2014 T6	-300 F	0.101	67*	59*	663	6*	2.4	10.7	57*	49*	5
6061 T6	-423 F	0.098	42*	35*	428	9*	8.5	10.1	35*	28*	3
7075 T6	-100 F	0.101	77*	66*	762	7*	4	10.5	55*	47*	5
Nickel Base Alloys											
Inconel 718	-423 F	0.296	180*	150*	608	16*	12	29.5*	172*	144*	5
Steel Alloys											
4140 (180 ksi)	-65 F	0.283	180*	165*	636	10*	7.5	29*	173*	146*	6
18-8 Mar-Aging	New alloy	0.289	240***	230***	830	12***	18	28.2***	232***	204***	8
Titanium Alloys											
Ti 5Al - 2.5 Sn	-300 F	0.161	115*	110*	714	10*	10	15.5*	94	87	5
Ti 6Al - 4 V	-300 F	0.160	155*	145*	969	5*	17	16.3*	136	119	8
*Reference 4 **Reference 11 ***Reference 12											

Table 9. MISDAS Study Project Material Properties and General Characteristics of Candidate Alloys, -150°F to 600°F

rties		600 F Properties				-150 F Properties					
/ρ (10³)	e (%)	F_{ty} (ksi)	F_{ty} (ksi)	F_{ty}/ρ (10^3)	e (%)	F_{ty} (ksi)	F_{ty} (ksi)	F_{ty}/ρ (10^3)	e (%)	Impact (Charpy v)	Other Characteristics
32	2*	160*	135*	578	3*	211*	195*	761	2*	2*	1. Good metals joining characteristics 2. Good corrosion resistance
21	4**	162**	138**	585	3.5**	195	189	704	12		
58	21*	126*	87*	441	19*	163*	102*	567	30*	56*	1. Poor weldability, good brazing characteristics 2. Excellent corrosion resistance
34	6*	12*	9*	119	14*	70	63	693	10	3.5	1. Good metals joining characteristics 2. Acceptable corrosion resistance
57	10*	8.6	6.3	98		47	37	479	10.5	9	1. Excellent metals joining characteristics 2. Good corrosion resistance
44	12.7*					82	71	812	10.8	4.5	1. Poor metals joining characteristics 2. Acceptable corrosion resistance
31	16*	167*	139*	564	19*	196*	161*	662	15*		1. Excellent metals joining characteristics 2. Excellent corrosion resistance
11	9*	158*	124*	558	13*	187	178	660		5	1. Good metals joining characteristics 2. Requires protective coating against the atmosphere
03	10.8***	212***	186***	733	11***	264	253	913		21	1. Good metals joining characteristics 2. Good corrosion resistance 3. Low temperature thermal (900 F aging) treatment facilitates ease of fabrication 4. Requires protective coating against the atmosphere
34	10*	74*	66*	460	13*	140	136	869	8.5	10	1. Coefficient of thermal expansion varies significantly from PH 14-8 Mo, the Apollo heat shield material. 2. Titanium welding requires special equipment. An inert atmosphere weld chamber is preferred. Welding most MISDAS components in a chamber would be impractical. 3. Good corrosion resistance against the elements.
50	5*	122*	98*	762	4.5*	216	198	1350		11	